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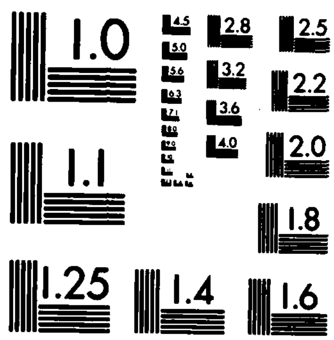

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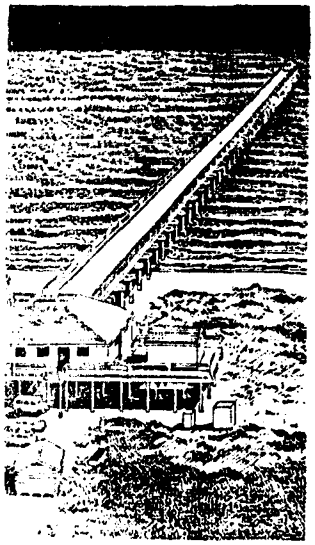

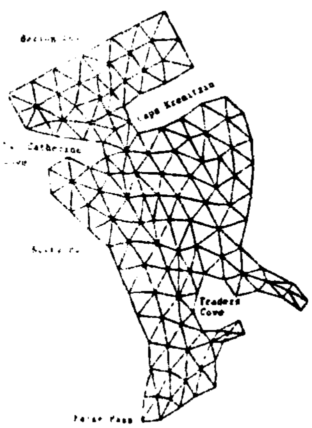

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BECHEVIN BAY, ALASKA INLET STABILITY STUDY

by

Yen-hsi Chu and H. S. Chen

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631
Vicksburg, Mississippi 39180-0631

May 1985

Final Report

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This report defines the stability of Bechevin Inlet, Alaska, as a part of the evaluation program for a potential navigation improvement project. The net flow transport, tidal prism of spring tide, and littoral transports are calculated with mathematical models based on published data. Conclusions and recommendations are given.

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PREFACE

The study summarized in this report was performed by the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), as requested by the US Army Engineer District, Alaska.

Technical analyses were performed by Dr. Yen-hsi Chu, Coastal Design Branch, CERC, and Dr. H. S. Chen, Coastal Oceanography Branch, CERC. This study was performed under the general supervision of Dr. Robert W. Whalin, Chief, CERC, Dr. William L. Wood, Chief, Engineering Development Division (EDD), Dr. James R. Houston, Chief, Research Division, Dr. Fred E. Camfield, Chief, Coastal Design Branch, and Dr. Edward J. Thompson, Chief, Coastal Oceanography Branch. At the time of publication, the Coastal Design Branch (formerly a branch of EDD) is a part of the Wave Dynamics Division where Mr. Claude E. Chatham is Chief.

Commanders and Directors of WES during the conduct of this study and the preparation of this report were COL Tilford C. Creel, CE, and COL Robert C. Lee, CE. Technical Director was Mr. Fred R. Brown.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC UNITS) OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.0283168	cubic metres
feet	0.3048	metres
knots (international)	0.5144444	metres per second
miles (US Statute)	1.609347	kilometres
square feet	0.092903	square metres
square miles (US Statute)	2.589998	square kilometres

BECHEVIN BAY, ALASKA, INLET STABILITY STUDY

PART I: INTRODUCTION

Site Area and Background

1. Bechevin Bay is a large tidal basin located at the southwestern end of the Alaska Peninsula (Figure 1). It connects Isanotski Strait and Ikatan Bay on the south to the Pacific Ocean and opens north to the Bering Sea through a wide tidal inlet, Bechevin Inlet. From False Pass to Cape Krenitzin, Bechevin Bay is about 12 miles* long, while the average width of the bay is 6.5 miles. The total surface area of the bay, including St. Catherine Cove, Traders Cove, Hotsprings Bay, and Hook Bay, is 78.7 square miles. Water depth at mean lower low water (mllw) varies from extreme shallow in the northern part of the bay to as deep as 550 ft in the south. The deepest portion of the bay is located between Traders Head and False Pass. There are several natural channels passing through the northern part of Bechevin Bay. The channel west of Cape Krenitzin has an average depth of 60 ft at mllw. Within the bay, the limiting channel depth is approximately 14 ft.

2. The northern portion of Bechevin Bay is shallow and full of sand bars and mud flats. Bechevin Inlet, which provides the opening of Bechevin Bay to the Bering Sea, is 1.7 miles wide but relatively short. Most of the inlet cross section is shallow and ranges from 1 to 3 ft at mllw, while water depth increases to about 100 ft at the eastern section near Cape Krenitzin. Bechevin Inlet, Bechevin Bay, and Isanotski Strait form an inlet system which separates Unimak Island from the Alaska Peninsula. This inlet system communicates with the Pacific Ocean and the Bering Sea and provides an ideal navigation route between the two oceans. From Kabuch Point to False Pass, Isanotski Strait is about 3 miles long with an average width of 0.5 mile. It has a mountainous shoreline and a rocky bottom and is rather deep (100 ft or more). During strength tide conditions the current in the strait is swift, from 4 to 7 knots. In this region, the limiting factor to navigation is the vessel length.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

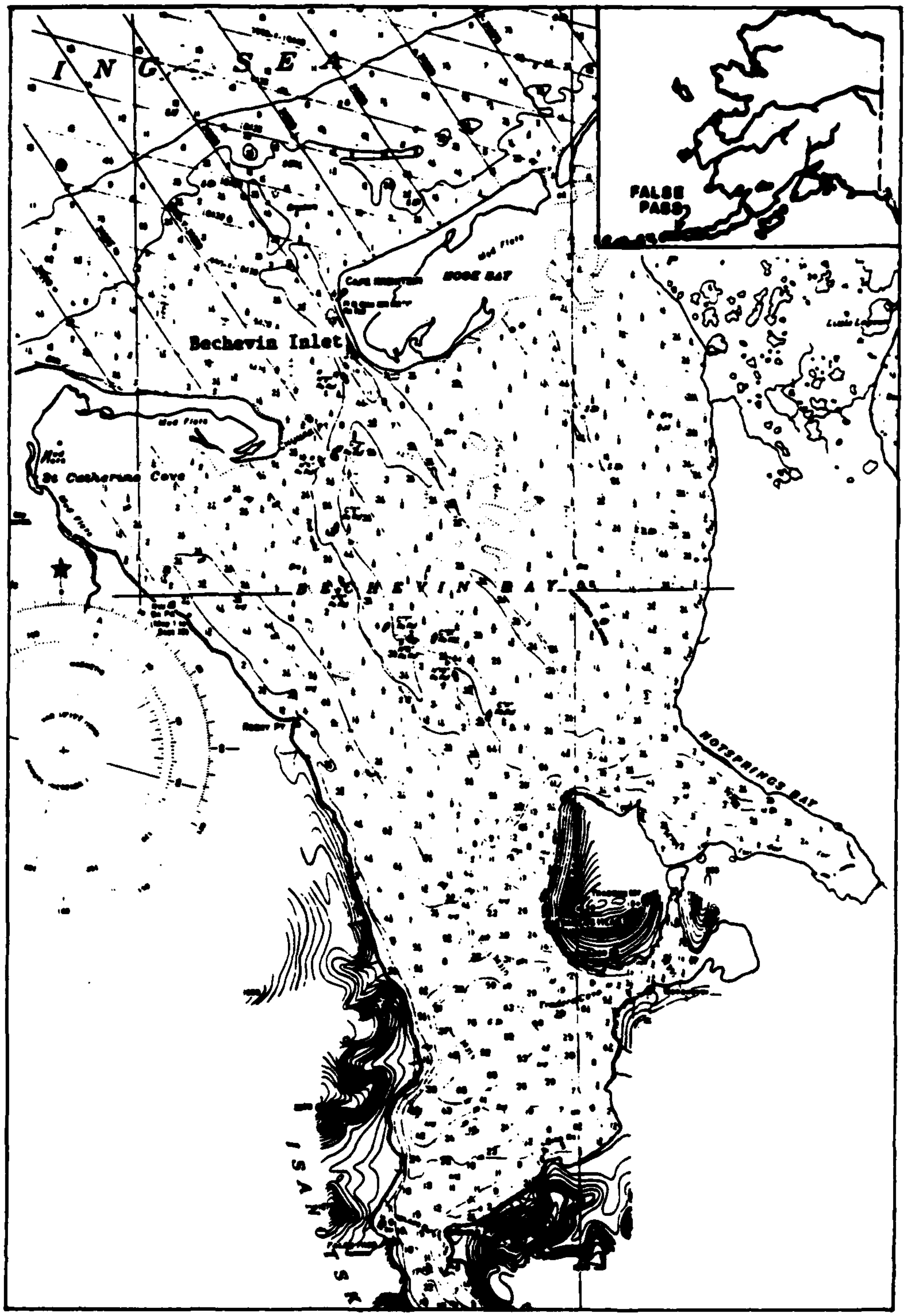


Figure 1. Bechevin Bay and Bechevin Inlet

According to Kriebel (1983) vessels over 200-300 ft in length would have difficulty maneuvering through the winding channel of Isanotski Strait.

3. The depth of natural channels at Bechevin Bay permits the passage of vessels with a draft less than 14 ft (National Ocean Service (NOS) 1984a). The presence of offshore bars at the deepwater edge of the Bering Sea north of Cape Krenitzin further limits the navigability of the Bechevin Bay inlet system. In fact, the village of False Pass derives its name from these limited passages to large vessels through Bechevin Bay. Presently, larger vessels enroute to Bristol Bay or the Bering Sea from the North Pacific must travel around Unimak Island through Unimak Pass. This route is 100-150 miles longer than the route through the Bechevin Bay Inlet system.

4. In the study of the American bottomfish industry's needs, the US Army Engineer District, Alaska (1982) identified the Bechevin Bay Inlet system as a potential site for navigation improvement and recommended further feasibility evaluation. Figure 2 shows the alternative channel routes investigated by the Alaska District. The desired improvements include dredging one of the three natural channels inside Bechevin Bay and cutting a channel through the offshore shoals to a depth of 20 ft or more below mllw. The present study is formulated to provide an in-depth office evaluation of the planned improvements, specifically the stability of Bechevin Inlet.

Problems and Needs

5. The prime engineering concern at this time is the maintainability of the dredged navigation channel, particularly in the area north of the inlet. Natural forces, such as wind waves and littoral currents, could frequently silt the improved channel, thus presenting a major obstacle in maintaining the channel at its desired depth. On the other hand, the tidal currents could potentially flush the sediment out of the channel and keep the maintenance effort at a minimal level. In addition, the potential erosion of beach material and the migration of the natural channel within the inlet could lead to an overall instability of the tidal inlet. Consequently, a stability analysis which provides qualitative predictions on the inlet responses to channel dredging is needed for Bechevin Inlet.

6. Hydrodynamically, Bechevin Bay is a unique tidal basin. It communicates with two oceans, the North Pacific and the Bering Sea. The available

Figure 2. Bechevin Inlet system and alternative channel routes

analytical techniques for the predictions of inlet hydraulic parameters and stability assessment, unfortunately, apply to inlets subjected to only one tidal influence. Therefore, special mathematical effort is needed to develop the hydraulic characteristics of the Bechevin Bay Inlet system. Published hydrographic and hydraulic data are the only data bases for the mathematical model simulations. Since results of calculation cannot be verified with field data at this time, they will be compared with available information such as the Tidal Current Table (NOS 1984b) and the US Coastal Pilot (NOS 1984a). This report documents the analytical methodologies, study results, and recommendations derived from the analytical techniques.

PART II: INLET HYDRODYNAMICS

Tides

7. The hydrodynamic characteristics of the Bechevin Bay Inlet system are influenced by tides from the North Pacific Ocean and the Bering Sea. Although there is no permanent tide reference station at the study area, the NOS includes both False Pass and St. Catherine Cove as subordinate tide stations. NOS' predictions on tide elevation at these two stations are referenced to the predictions made for the permanent tide station at Dutch Harbor, Alaska, which is approximately 130 miles southwest from the study area. The type of tide in this area is complex. It is semidiurnal around the times the moon is over the equator but becomes diurnal around the time of maximum north or south declination of the moon (NOS 1984b). The following information is obtained from NOS' 1984 Tide Table:

Location	Mean Range ft	Diurnal Range ft	Mean Tide Level ft
False Pass	2.1	4.1	2.4
St. Catherine Cove	2.6	4.7	2.9

The mean tide levels at both locations are referenced to local mllw datums. Correlations between local mllw and National Geodetic Vertical Datum (NGVD) are not known at this time. Tides at St. Catherine Cove generally lag tides at False Pass by approximately 2 hr.

Tidal Prism

8. By definition, the tidal prism is the amount of water moving in and out of the tidal basin excluding the freshwater inflow. The simple method commonly used for estimating a tidal prism is to multiply the basin surface area by the tidal range. This method is not accurate and its application to Bechevin Inlet is questionable because of the bay's connection with two oceans and the 2-hr phase difference between the north and south ends of the bay. Therefore, a one-dimensional tidal flow model was used to calculate the tidal flow at Bechevin Inlet. This model is essentially the continuity equations governing the relationship between the basin area A, tidal elevation at bayside h, and the multiple tidal flows Q_i, i.e.,

$$A \frac{dh}{dt} = Q_1 + Q_2$$

where t is the time, and Q_1 and Q_2 are the tidal flows, respectively, at Bechevin Inlet and False Pass. Positive values of Q_i represent the flooding phase of tides (flow moves into the basin), while negative values of Q_i represent the ebbing phase of tides (flow moves out of the bay). The tidal flow at False Pass Q_2 was directly calculated from the tidal currents predicted by NOS and the channel cross-sectional area at False Pass. The boundary layer effect was corrected by assuming that the mean current velocity is 80 percent of the postulated tidal velocity at False Pass. Since the continuity equation involves only the incremental change in the basin elevation, the exact tidal height is not important to the determination of the Q_1 value. The simultaneous average tidal heights of False Pass and St. Catherine Cove were used to represent the water level of the entire Bechevin Bay.

9. Figure 3 illustrates the tidal flows simulated for the 4-day period of 1-4 January 1984. The predicted tidal elevations at False Pass and St. Catherine Cove are also shown in Figure 3. Several interesting features are revealed by this figure. First, both tides at False Pass and St. Catherine Cove exhibit strong diurnal characteristics, while the tidal flows at Bechevin Inlet are distinctly semidiurnal. Spring tide occurred during the period of 1-4 January 1984. It is noted that the tidal flow at Isanotski Strait during this period was semidiurnal, while the tidal flow at Unimak Pass (not too far southwest from the study area) was, interestingly, diurnal. Second, the phase of tidal elevation at St. Catherine Cove does not seem to correlate with the phase change of the predicted tidal flow at Bechevin Inlet; i.e., the flood tide at the inlet in some instances corresponds to a reduction in water elevation at St. Catherine Cove or vice versa. In this report, flood tide implies the current is moving into the tidal basin, and ebb tide implies the current is moving out of the basin. This unconventional relationship between tidal current and tide height is an apparent effect due to the double ocean connection of the inlet system.

10. The one-dimensional tidal flow model simulates six flood tides and seven ebb tides. The tabulation below lists the tidal flow volumes calculated with the tidal flow model. At Bechevin Inlet, the average flood flow volume is 14.07×10^9 ft^3, and the average ebb flow volume is 18.79×10^9 ft^3. The difference in flow volumes implies that there is a net flow transferred

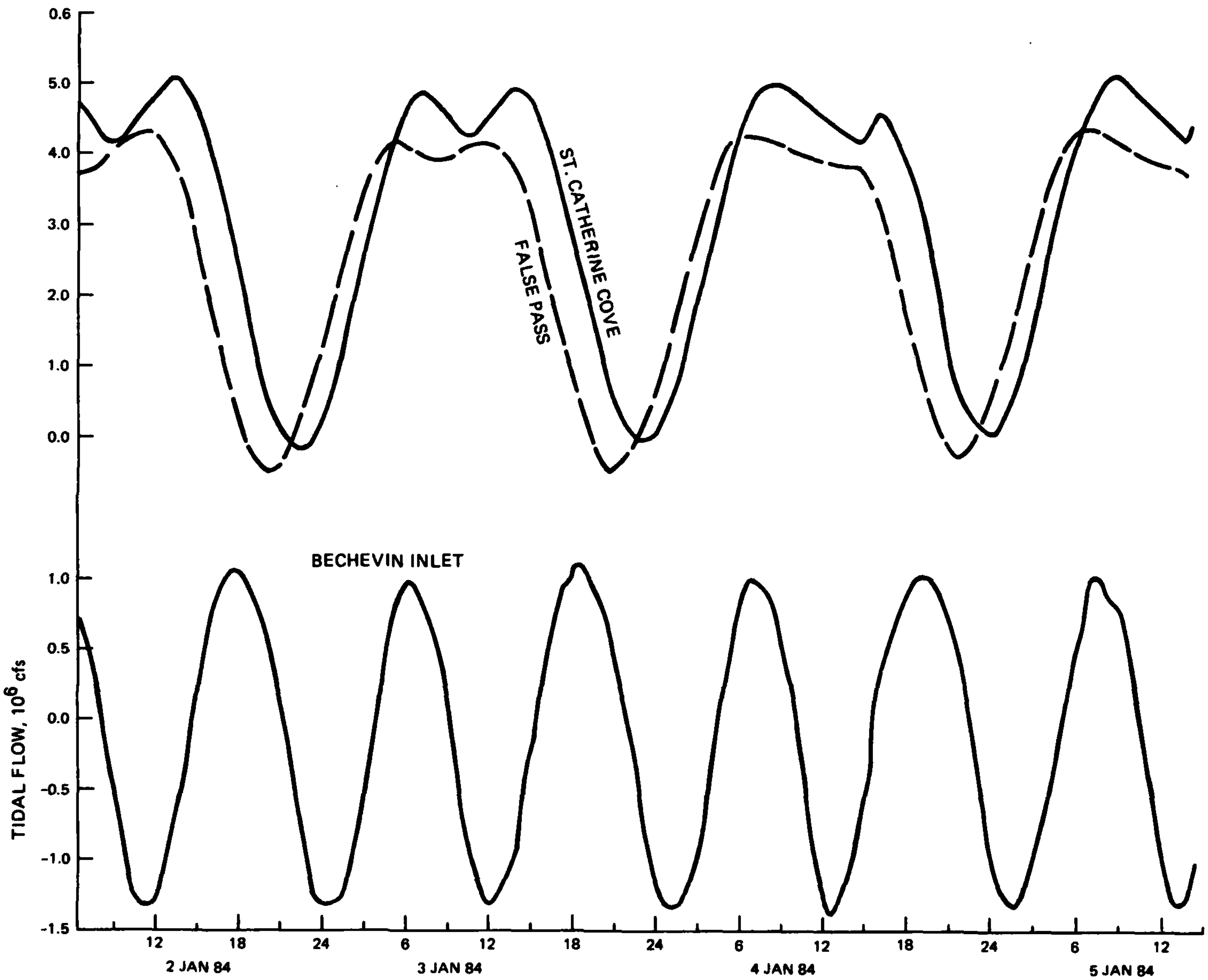


Figure 3. Tidal characteristics of Bechevin Bay Inlet system

Tidal Flow Volume

1-4 Jan 1984

	Bechevin Inlet		False Pass	
	Flood	Ebb	Ebb	Flood
	--	18.95	--	19.01
	16.88	20.38	25.20	28.58
	11.48	19.15	10.27	17.19
	16.16	18.27	24.55	28.85
	11.95	17.71	10.42	16.43
	15.89	19.96	23.92	27.90
	12.04	17.14	10.06	15.57
Avg	14.07	18.79	17.40	21.93

Note: Values shown are in 10^9 ft^3. Tidal volumes are calculated for spring-tide conditions.

from Ikatan Bay to the Bering Sea. This net flow transfer volume is 4.72×10^9 ft^3 per tidal cycle during the studied 4-day period It is expected that this net flow occurs during other tide conditions as well, probably at smaller magnitudes. Like freshwater inflow to a single ocean-connected tidal basin, the net flow from Ikatan Bay is an important factor for flushing the sediment out of Bechevin Bay. Since the freshwater inflows should be excluded as part of the tidal prism, the flood flow volume of 14.07×10^9 ft^3 was used as the tidal prism corresponding to spring tides at Bechevin Inlet.

Tidal Current in Bechevin Bay

11. Tidal current is one of the two major factors affecting the stability of Bechevin Inlet, the formation of the offshore sand bars, the formation of Chunak Spit, and the stable or accretional shoreline lobe at Cape Krenitzin (Kriebel 1983). Naturally it is of vital importance to obtain tidal current velocity and to depict tidal flow circulation patterns in Bechevin Bay and its vicinity in the Bering Sea for the False Pass channel navigation improvement study. Since there are practically no current data available in the bay area, a two-dimensional hydrodynamic model (Chen 1978) was employed to calculate tidal current velocity.

Tidal Current Model

12. The tidal current model is based on the two-dimensional depth integrated continuity and momentum equations with the Boussinesq approximation as follows:

$$\frac{\partial H}{\partial t} + \nabla \cdot \vec{q} = Q \tag{1}$$

$$\frac{\partial \vec{q}}{\partial t} + \nabla \cdot \left(\frac{\vec{q}\vec{q}}{H}\right) + \vec{f} \times \vec{q} = - \frac{H}{\rho_o} \nabla \left(p^s + \rho g \eta\right) + \nabla \cdot \tilde{\tau} + \frac{\vec{\tau}^s - \vec{\tau}^b}{\rho} \tag{2}$$

where

H = total water depth

$\vec{q}$ = (q_x, q_y), water transport vector

Q = external inflow

$\vec{f}$ = Coriolis vector

p^s = atmospheric pressure

$\rho = \rho_o + \nabla\rho$ = water density

g = acceleration of gravity

η = free surface displacement

$\tilde{\tau}$ = internal stresses tensor

$\vec{\tau}^s$ = wind stress vector

$\vec{\tau}^b$ = bottom stress vector

This model is a real-time finite element model. Detailed description and development of the model are provided by Chen (1978).

Input Data to Tidal Current Model

13. NOS map 16535 (NOS 1976) was used to provide the information on coastline configuration and bathymetry for the geometric input data to the model. The finite element network of Bechevin Bay and its proximity to the Bering Sea are shown by Figures 4, 5, and 6. Figures 5 and 6, respectively, illustrate the nodal and element locations. The typical length of an element ranges from 0.9 to 2.0 km. Figure 7 shows the locally averaged mean water depth, which is the mllw depth plus one-half of the mean diurnal range of the tide, about 0.7 m.

14. Input data of tides and tidal currents in the bay and its proximity

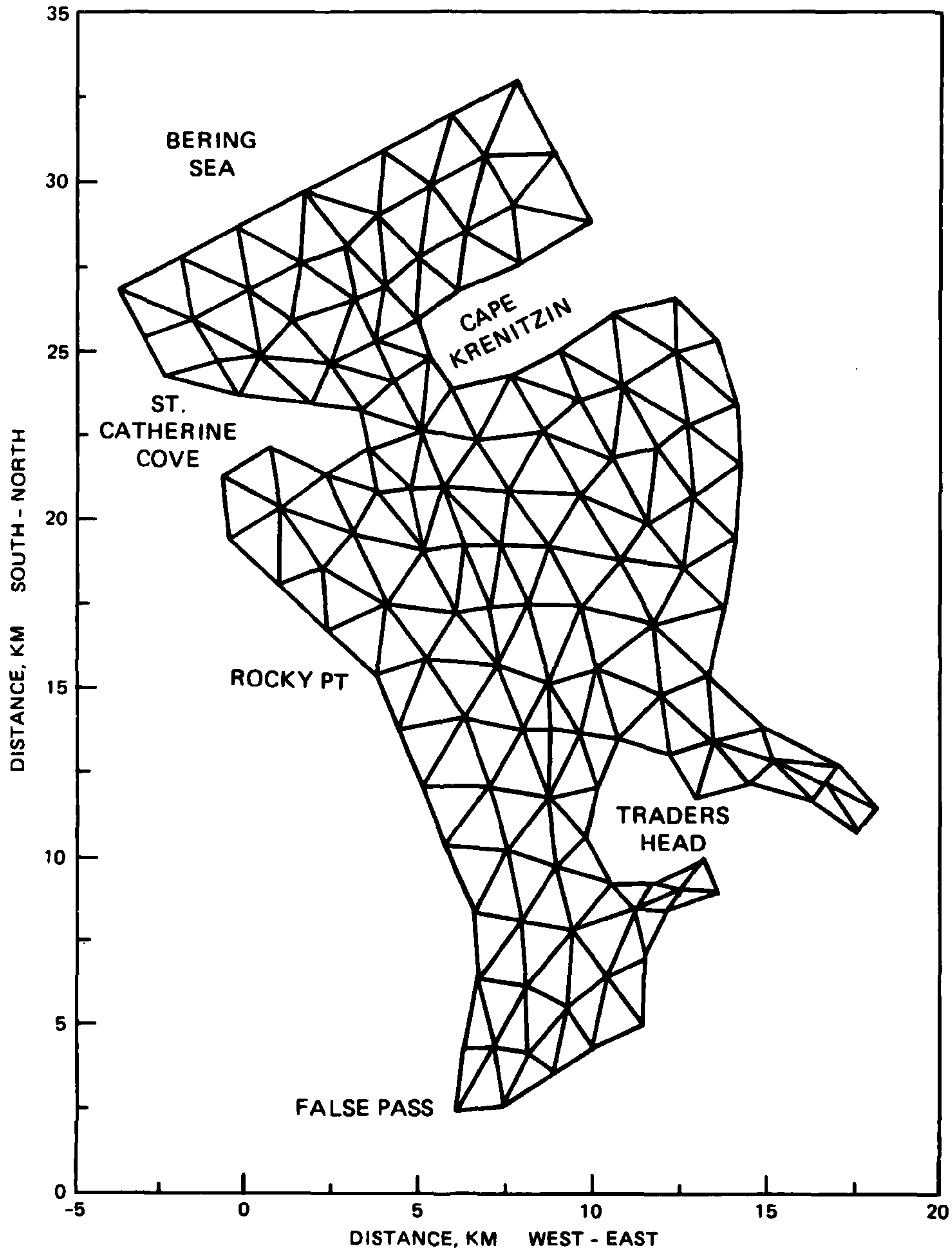


Figure 4. Finite element network of Bechevin Bay

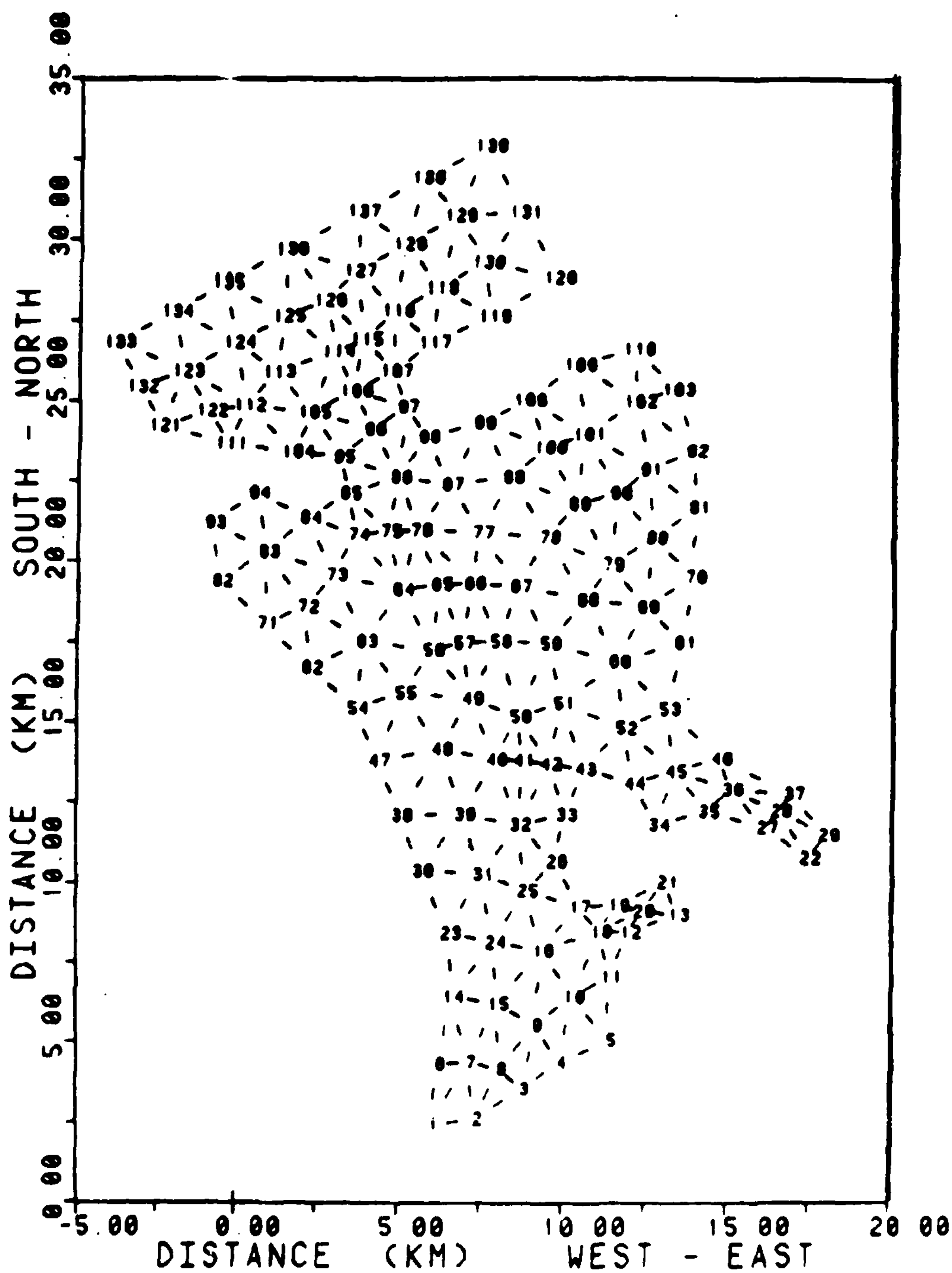


Figure 5. Nodal numbering of Bechevin Bay model

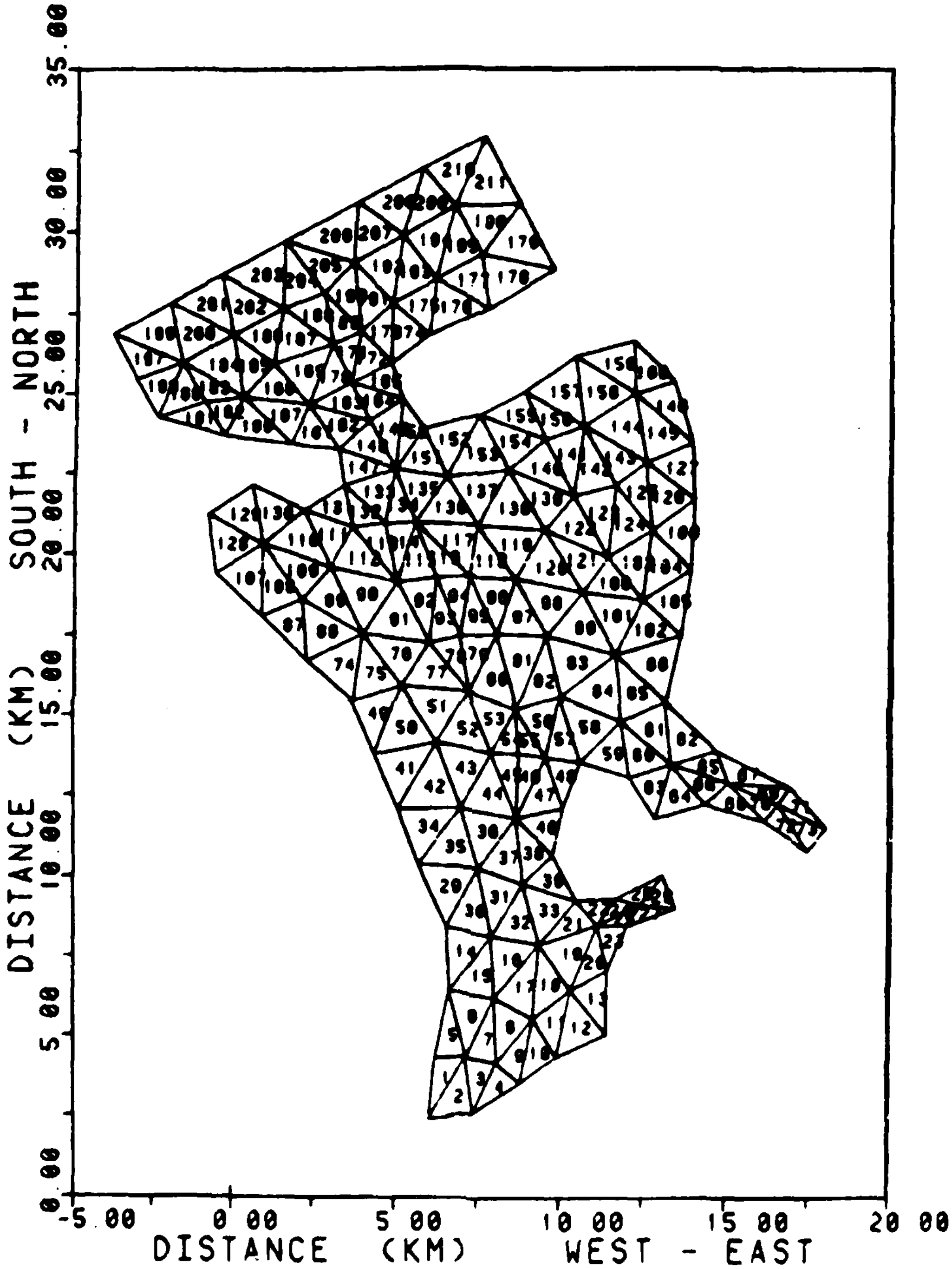


Figure 6. Element numbering of Bechevin Bay model

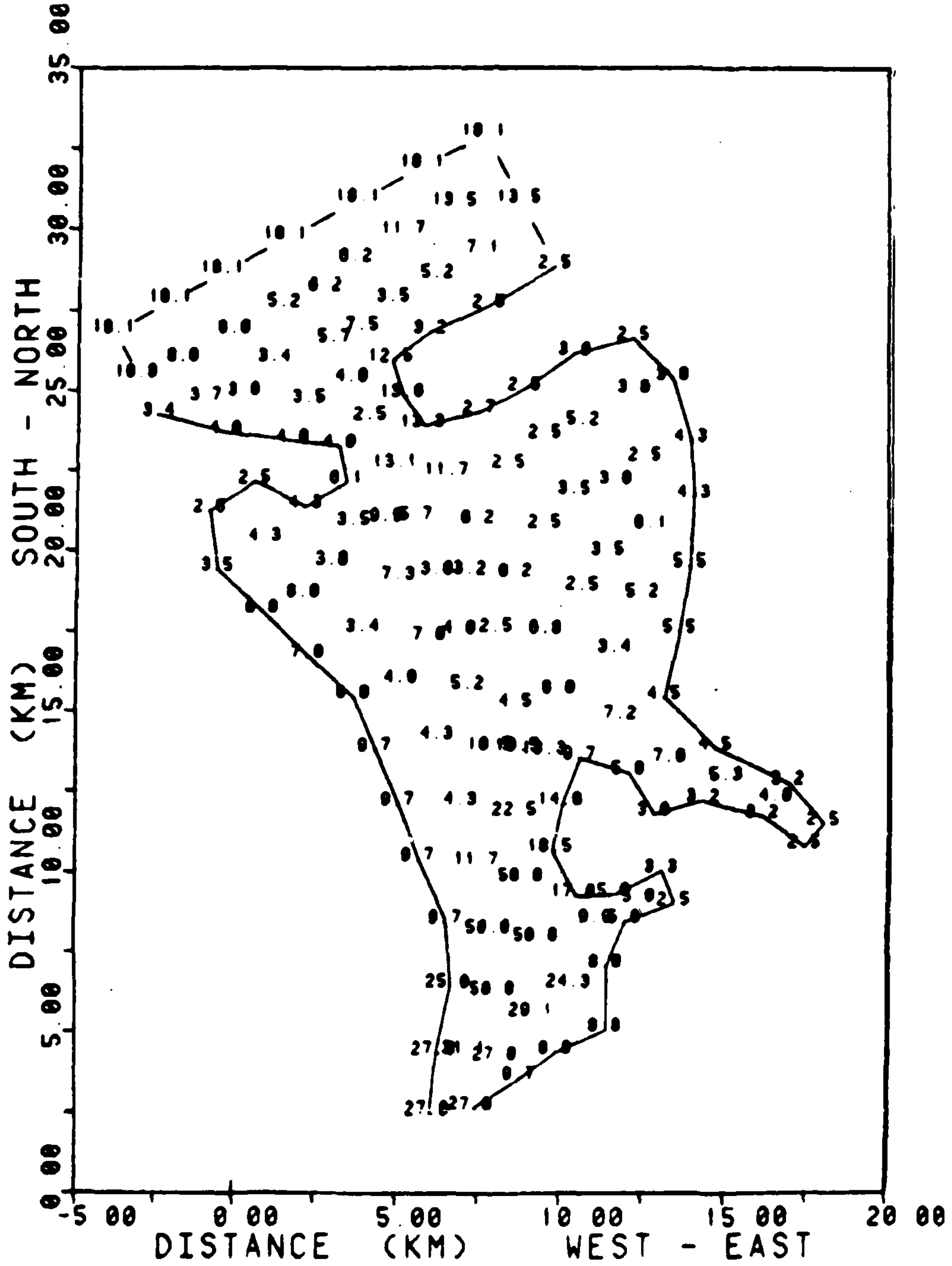


Figure 7. Nodal water depth of Bechevin Bay model

to the Bering Sea can be obtained only from the NOS Tide Tables (NOS 1984c) and Tidal Current Tables (NOS 1984b), since there are no other data available for the study area. In the Tide Tables there are only two subordinate stations at False Pass and St. Catherine Cove (see Figure 1 for the locations) listed for tide information. These two stations are referred to the reference station at Dutch Harbor, Alaska. There are, however, no tide data in the vicinity of the Bering Sea to provide the input data for the boundary condition of the model. Therefore, the tide input data in the Bering Sea are estimated from the nearby tide stations, and the values are given in Table 1. The insufficiency of the tide data for the boundary condition of the Bering Sea could affect accuracy of the calculated results to some degree. Tidal elevation at False Pass, used as the boundary condition, is approximated by fitting one-half the period of the cosine curve between each high and low water or low and high water. The high and low waters listed in the following tabulation are obtained from the reference station at Dutch Harbor with the corrections of both time and height differences. The water levels are further adjusted by using its mean water level (0.73 m (2.4 ft) mllw) as the datum.

Time January 1984 day	hr	min	Height of High and Low Waters m
7	08	37	0.50
8	00	12	-0.50
	08	52	0.50
	15	24	0.00
	17	58	0.10
9	00	47	-0.40
	09	03	0.50
	15	35	-0.10
	20	00	0.00
10	01	12	-0.20
	09	10	0.50
	15	50	-0.20
	21	44	0.00

15. In the Tidal Current Tables (NOS 1984b) there is one reference station at False Pass (Isanotski Strait) and one subordinate station near Rocky Point (Bechevin Bay). The maximum flood and ebb currents at False Pass are twice as big as those near Rocky Point. In the calculation, the tidal current input at False Pass is approximated by fitting one-quarter period of sine or

cosine curves between the maximum flood or ebb current and zero current. The maximum flood/ebb currents and zero current are directly obtained from the Tidal Current Tables and are listed as follows:

Time January 1984			Maximum Flood and Ebb Currents and Zero Current	
day	hr	min	knots	m/sec
7	21	44	2.6E	1.34E
8	00	51	0.0	0.00
	03	59	3.5F	1.80F
	08	13	0.0	0.00
	10	48	2.1E	1.08E
	14	04	0.0	0.00
	16	17	2.5F	1.29F
	19	04	0.0	0.00
	22	29	2.3E	1.28E
9	01	23	0.0	0.00
	04	34	3.4F	1.75F
	08	43	0.0	0.00
	11	35	2.2E	1.13E
	14	59	0.0	0.00
	17	10	2.4F	1.24F
	20	11	0.0	0.00
	23	15	2.0E	1.03E
10	01	58	0.0	0.00
	05	15	3.3F	1.70F
	09	11	0.0	0.00
	12	18	2.3E	1.18E
	15	53	0.0	0.00
	18	11	2.5F	1.29F
	21	36	0.0	0.00

Numerical Results of Tidal Current Simulation

16. Calculations of tidal currents are performed for three cases: (a) the existing bathymetric condition, in which the mllw depth in the NOS map is used; (b) the 25-ft case, in which mllw depth less than 25 ft along the proposed channel route (Figure 8) is dredged to 25 ft; and (c) the 30-ft case, in which mllw depth less than 30 ft along the proposed channel route is dredged to 30 ft. The choice of using 25 and 30 ft for dredging criteria is to determine hydrodynamic responses of the inlet system to channel improvements. The depth of 20 ft mllw was not used in the evaluation because the effects on numerical results associated with this depth would not

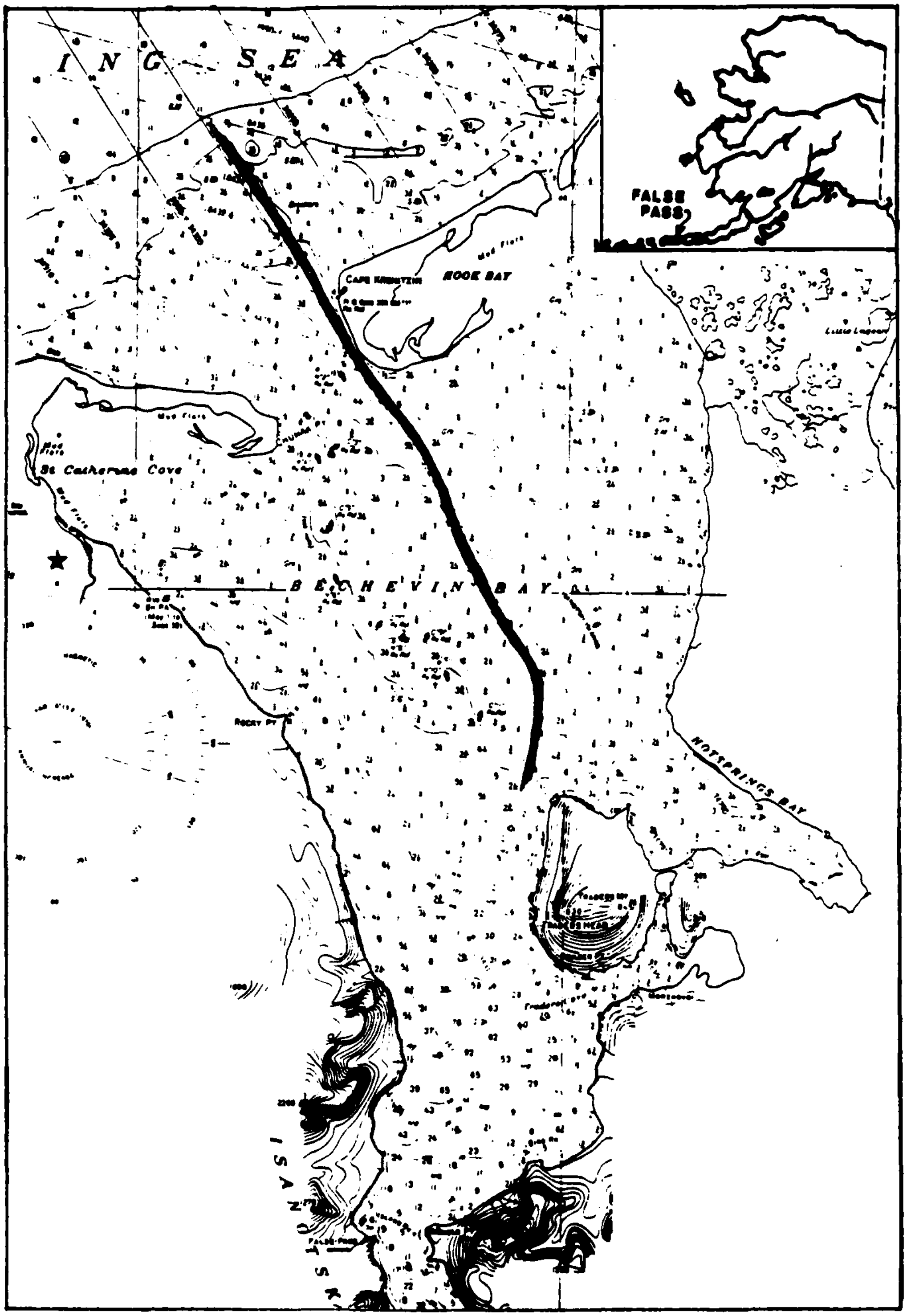


Figure 8. Channel route for tidal current model simulation

be sensitive enough for a definitive conclusion. Although calibration and verification of the model are not performed in this study, due to the lack of observed data, the calculated results of tidal elevation and current from the three cases are all within reasonable range.

The existing case

17. Figure 9 illustrates the calculated tidal elevations at element 2 (near False Pass), element 149 (Bechevin Inlet), and element 189 (outside the inlet) (see Figure 6 for element location). They are mixed tides as evidenced in the large inequality in either the high and/or low water heights, with two high waters and two low waters occurring each tidal day. The tides in the other period of time may differ both in type and magnitude from the present case, as illustrated by the typical tide curves at Dutch Harbor in the Tide Tables.

18. Figure 10 illustrates the calculated tidal flow velocity vectors at several locations inside and outside the bay. Additional vector plots for the existing case are given in Plates 1-8. Note that during a tidal cycle there is a large water volume flowing into the bay at element 2 near False Pass and a large net water volume flushing out of the bay at element 149 in the inlet. Therefore, the result which shows water movement from the North Pacific through the bay to the Bering Sea is consistent with the finding from the one-dimensional tidal flow model. Figures 11a and 11b illustrate the Eulerine description of the flow circulations when incoming or outgoing currents are nearly maximum at the tidal entrance.

The 25- and 30-ft cases

19. The calculated tidal heights for the 25- and 30-ft cases are almost the same as those for the existing case shown by Figure 5. The changes in tidal current velocity for the three cases are typically given at elements 2, 149, and 189 as shown in Table 2. At element 2 near False Pass, the maximum currents increase slightly (about 1 percent or less), being about 0.003 m/sec for the 25-ft case and 0.007 m/sec for the 30-ft case, relative to the existing case. A close examination of the data listed in Table 2 can reveal that the increase in flood current is slightly higher than the increase in ebb current, an indication that deepening the navigation channel would increase the net flow volume through the Bechevin Inlet system. At element 149 in the inlet throat, the maximum currents increase 2.6 percent (0.012 m/sec) in incoming or flood tidal current ("incoming," here, denotes flow from the Bering Sea

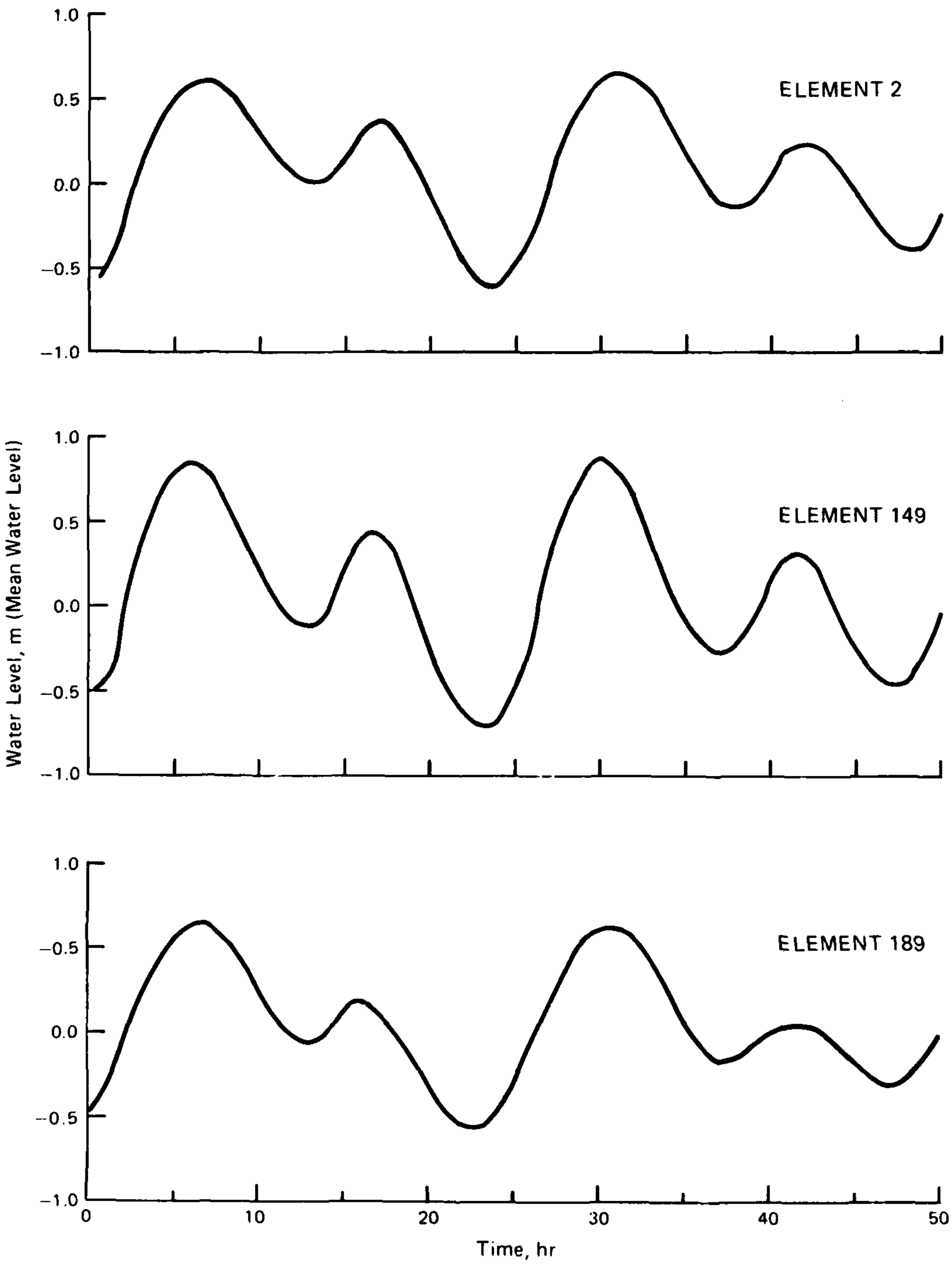


Figure 9. Water level versus time for existing case

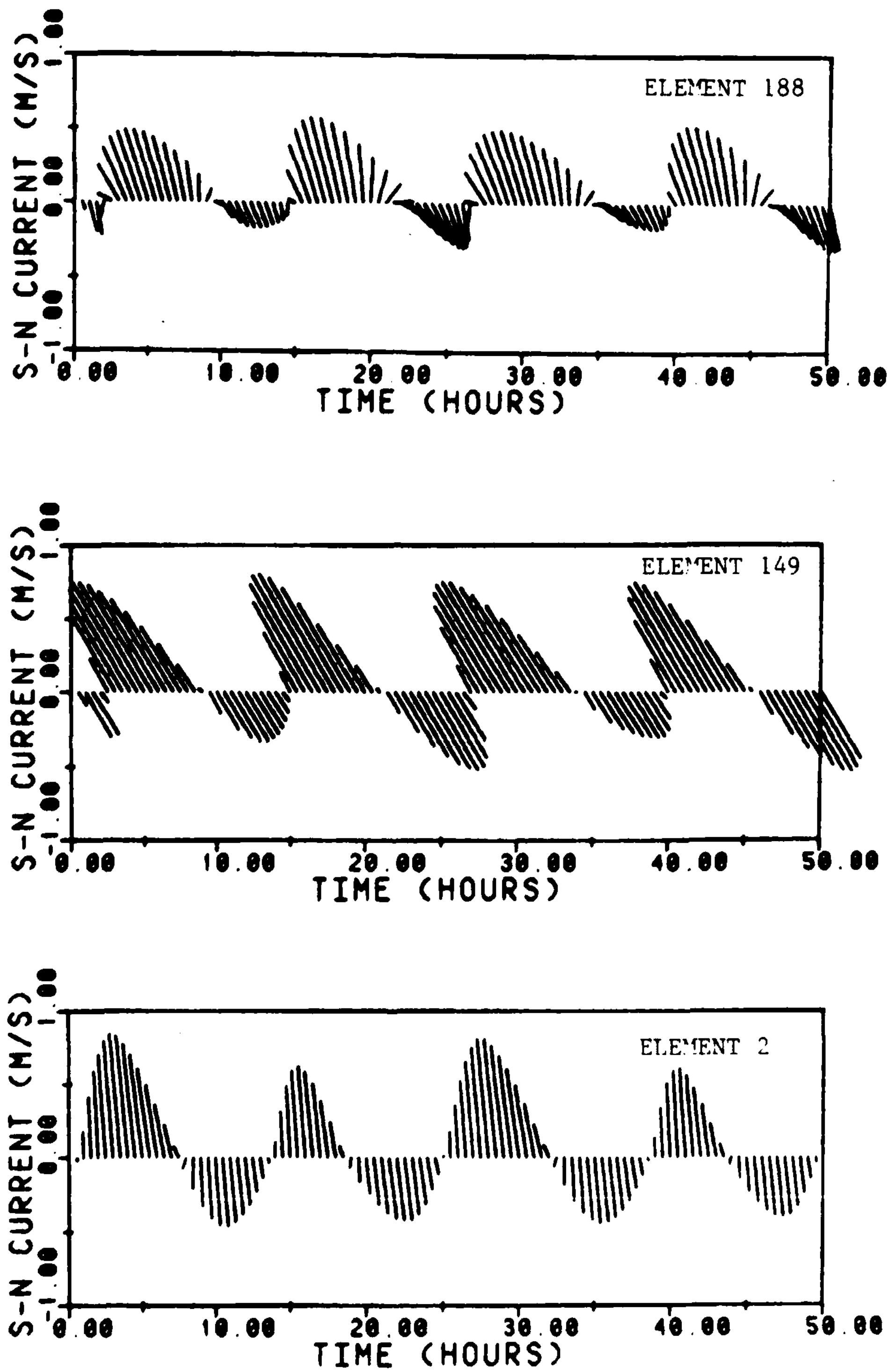
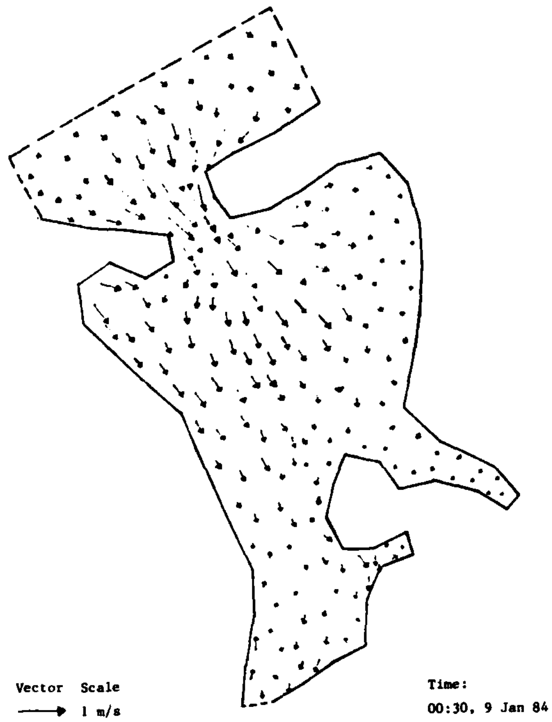
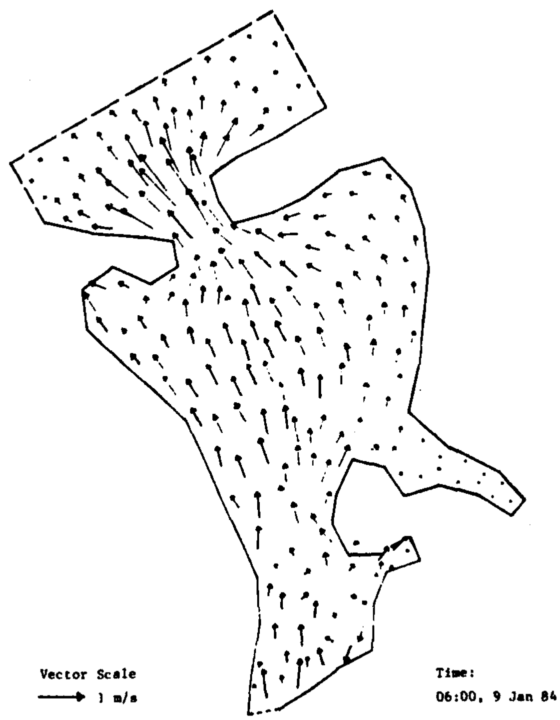


Figure 10. Tidal current vector versus time at selected elements--existing case



a. Flood tide at Bechevin Inlet



b. Ebb tide at Bechevin Inlet

Figure 11. Flow circulation at Bechevin Bay and vicinity

through the inlet to the bay, and "outgoing" from the bay to the sea) and 1.7 percent (0.015 m/sec) in outgoing or ebb tidal current for the 25-ft case. They increase 5.8 percent (0.027 m/sec) in incoming tidal current and 4.1 percent (0.036 m/sec) in outgoing tidal current for the 30-ft case, relative to the existing case. At element 189, outside the inlet, the maximum currents decrease 3.2 percent (0.020 m/sec) in incoming tidal current and 3.3 percent (0.020 m/sec) in outgoing tidal current for the 25-ft case. They decrease 8.0 percent (0.025 m/sec) in incoming tidal current and 8.3 percent (0.051 m/sec) in outgoing tidal current for the 30-ft case, relative to the existing case.

PART III: LONGSHORE LITTORAL TRANSPORT

Wind Waves

20. Wave data statistics compiled by the Arctic Environmental Information and Data Center (AEIDC 1977) were used for potential longshore littoral transport analysis. Figure 12 shows the annual wave rose, representing the marine area of Bristol Bay and the nearby Bering Sea area, offshore of the Alaska Peninsula. Since the AEIDC data came from primarily surface marine observations, wave heights tend to be slightly underestimated by observers on transient ships. No correction efforts were made in this study. Figure 12 was derived from 24,000 observations spread over the 12 calendar months. It indicates waves from west and northwest are more frequent than waves from other directions in the open area. Table 3, obtained from the AEIDC (1979), lists the annual wave height and direction in percentage of time at the same same marine area.

Potential Longshore Transport Rates

21. Longshore sediment transport was calculated by using the energy flux method i.e., Equation 4-54 of the Shore Protection Manual (SPM 1984). This equation states that

$$Q_{\ell} = 2.03 \times 10^{6} f\ H_o^{5/2}\ F_o(\alpha_o)$$

where

Q_{ℓ} = potential longshore transport rate, m^3/yr

f = frequency of occurrence

H_o = deepwater significant wave height, m

$F_o(\alpha_o) = (\cos \alpha_o)^{1/4} \cdot \sin 2\alpha_o$

α_o = angle between deepwater wave crest and shoreline, deg

22. Because the directional wave data of the present study are presented by 45-deg sectors, average values of F_o over the 45-deg sectors $\overline{F}_o$ were used in the equation for the longshore transport computations. $\overline{F}_o$ is calculated by

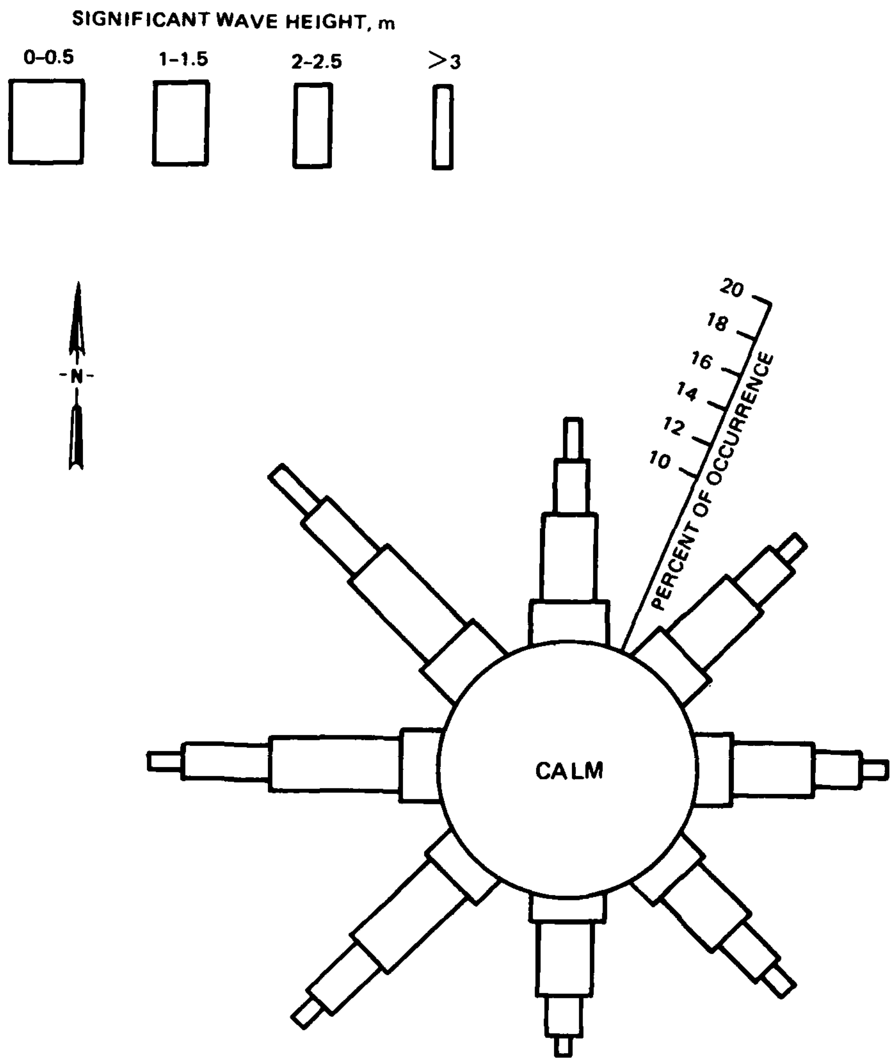


Figure 12. Wave rose, Bering Sea off Bechevin Inlet

$$F_o = \frac{4}{\pi} \int_{\alpha_1}^{\alpha_2} F_o(\alpha_o)\, d\alpha_o$$

where α_1 and α_2 are the angles of the two extreme segments covering the wave data reported in the same direction. When the 45-deg sector includes either the shoreline or the shoreline normal, special care is required to perform the averaging computations (Section V-2, Chapter 8, SPM 1984).

23. The azimuth angle of the coastline at Bechevin Inlet varies from 52 deg on the west to 90 deg on the east side of the inlet. The potential longshore transports were calculated for each of these two shoreline angles. Table 4 shows the longshore transport rates calculated according to the SPM method. The results are summarized in the following tabulation which

Summary of Longshore Transport Analysis

	Shoreline Angle, deg		
	52	90	Average
$(Q_\ell)_{SW\ or\ W}$	$2.239 \times 10^6\ m^3/yr$	$1.637 \times 10^6\ m^3/yr$	$1.938 \times 10^6\ m^3/yr$
$(Q_\ell)_{NE\ or\ E}$	$3.172 \times 10^6\ m^3/yr$	$2.802 \times 10^6\ m^3/yr$	$2.987 \times 10^6\ m^3/yr$
$(Q_\ell)_{net}$	$0.933 \times 10^6\ m^3/yr$	$1.165 \times 10^6\ m^3/yr$	$1.049 \times 10^6\ m^3/yr$
$(Q_\ell)_{gross}$	$5.411 \times 10^6\ m^3/yr$	$4.439 \times 10^6\ m^3/yr$	$4.925 \times 10^6\ m^3/yr$

shows the slight difference in transport rate due to the difference in shoreline angle. Both results consistently indicate that the net littoral transport is toward the east or northeast on the right side of the inlet. The average value of this net transport is $1.05 \times 10^6\ m^3/yr$, while the average gross transport rate is $4.9 \times 10^6\ m^3/yr$. It is noted that the calculated transport rates are higher than those reported for other US coastal locations (Table 4-7, SPM 1984). Whether these higher rates are caused by the extreme wave climate at the Bering Sea area or by the inapplicability of AEIDC data to the coastline of interest cannot be ascertained at this time. These higher than normal estimates in sediment transport could result in a conservative stability number (to be discussed later in this part). For Bechevin Inlet, the AEIDC's shipboard data are the only data available to the study area. The result of the analysis indicates that the littoral transport at the study area is fairly active and that the dominant direction of littoral transport is toward the right side of the inlet.

Stability of Inlet Entrance

24. It is important to note that the current theories related to inlet stability are only approximations. An inlet which is stable during ordinary weather may become unstable during a severe storm. The available theories are empirical and subject to revision as additional information is accumulated. The methods presented by O'Brien (1931, 1966) and Escoffier (1940, 1977) relate inlet stability to inlet hydrodynamics, specifically the relationship among the maximum tidal velocity at inlet throat, throat cross-sectional area, and tidal prism. According to O'Brien (1966) the sediment characteristics at the inlet are not significant parameters to the stability consideration. The effect of wind waves on inlet stability has been discussed by Johnson (1973) and O'Brien (1976); however, the relationships proposed still remain to be tested by field observation. The significance of littoral drift on stability is considered by Carothers and Innis (1960) and by Bruun (1968, 1973, 1978). Criteria proposed by Bruun specifically relate the annual rate of sand transport into the inlet and the tidal prism corresponding to the spring range of tide. The present study uses these available methods to assess the stability of Bechevin Inlet.

25. O'Brien's stability concept relates the minimum throat area Ac below mean sea level (msl) and the tidal prism Ω at the spring tides by the following relationship:

$$Ac = b\ \Omega^N$$

According to Jarrett (1976), the corresponding empirical values of b and N for inlets on the Pacific coast with one or no jetties are 1.91×10^{-6} and 1.10, respectively. These two numerical values are valid only when Ac is expressed in ft^2 and Ω in ft^3. Using the calculated tidal prism, $14.07 \times 10^9\ ft^3$, the minimum throat area Ac is calculated to be $2.78 \times 10^5\ ft^2$. This cross-sectional area is significantly larger than the area determined from NOS Nautical Chart 19635 (NOS 1976), $2.02 \times 10^5\ ft^2$, but still within the 95 percent confidence limits of the correlation. The result suggests that Bechevin Inlet is slightly unstable and may be subject to scouring. If the tidal flow storage capacity of Bechevin Bay, $10.95 \times 10^9\ ft^3$ (obtained by multiplying the bay area by the tidal range), is used to approximate the tidal prism Ω, then the Ac value would be $2.11 \times 10^5\ ft^2$, which is close to

the value determined from inlet bathymetry, 2.02×10^5 ft^2. According to Kriebel (1983), the beach at Cape Krenitzin seems stable in recent years. A tendency of inlet scour could be viewed as a favorable indication that the throat section will be maintained at least at the present depth.

26. Bruun's criterion relates the tidal prism Ω to the littoral drift M, the two dominant forces that determine the overall stability of a tidal inlet. The tidal prism characterizes the flushing ability of an inlet, while M represents the wave energy in terms of longshore transport rate. Bruun (1978) defines M as the annual longshore sediment volume carried into the inlet. The ratio of Ω/M defines the overall stability number. The criteria suggested by Bruun (1978) are as follows:

Ω/M	Inlet Condition
>150	Conditions are relatively good, little bar and good flushing. (Good)
100-150	Conditions become less satisfactory, and offshore bar formation becomes more pronounced. (Fair)
50-100	Entrance bar may be rather large, but there is usually a channel through the bars. *(Fair to Poor)*
20-50	All inlets are typically "bar-bypassers." Waves break over the bar during the storm, and the inlets "stay alive" because they often get "a shot in the arm" from fresh-water flows during the stormy season. For navigation, they present "wild cases" which are unreliable and dangerous. (Poor)
<20	Entrances are unstable "overflow channels" rather than permanent inlets. (Poor)

27. The method for estimating the annual sediment volume into the inlet M has never been clearly outlined. Since Bechevin Inlet is a downdrift offset inlet which has a strong tendency to receive a large portion of the littoral material, the present study conservatively assumes that the value of M equals the gross annual littoral transport rate, i.e., 4.9×10^6 m^3. By using the value of 14.07×10^9 ft^3 (3.98×10^8 m^3) for the tidal prism, the overall stability number for Bechevin Inlet is 81. According to Bruun's criteria, this inlet has a good flushing with formation of large entrance bars, but there is usually a channel through the bars passable by shallow draft

vessels. This assessment appears consistent with the present condition at Bechevin Inlet. The value of 81 should be considered as the lower end of stability assessment; the conservatism is mainly derived from the possibly overestimated M value. As stated in paragraph 23, the calculated longshore transport rate, net or gross, is significantly higher than the published values for other US coastal locations. The wave climate at the Bristol Bay area seems to be comparable to that off the Atlantic Coast at the deepwater region (Corson, et al. 1981). However, the predicted longshore transport rate at the Bechevin Inlet area is nearly 3 to 5 times higher than that reported for the Atlantic Coastal region. It is quite possible that the M values used in the present analysis are overestimated by a factor of 2. The overall stability number may therefore fall within the range between 81 and 162. According to Bruun's criteria, the overall stability condition at Bechevin Inlet is "fair."

28. The improvement of navigation channels by dredging will result in a small increase in tidal current velocity at the inlet area, thus causing a small increase in tidal prism. The overall effect on inlet stability number, however, will be small. Dredging offshore would reduce the tidal current slightly at the navigation channel route (Table 3, element 189). Thus, shoaling is expected to occur at the offshore channel. It is interesting to note that the reduction in channel cross section offshore would increase the tidal current velocity, and vice versa, according to the tidal current model. This is the condition of a stable channel, a criterion suggested by Escoffier (1977). Stable channel depth is about 12 ft mllw according to Kriebel (1983). It is logical to conclude that dredging offshore will lead to sedimentation at the offshore channel toward its equilibrium depth or stable depth. It is not possible to predict the natural response time to the perturbation caused by dredging. Except for conditions of severe storms, the natural shoaling processes probably will be slow. Maintenance dredging requirements, which can be significant, should be determined by the frequency and extent of severe storm events.

29. Corson (1983) hindcasted the storm wave heights for the open coast area off Bechevin Inlet and reported an average wave height of 7.75 m for 20 yearly storm events. The wave height associated with the storm event, which recurred once a year, is approximately 4.9 m. According to Table 3, waves ranging from 4 to 5.5 m or higher occur 6.1 percent of the time (or

22 days) in a year. At these heights, waves would break at the nearshore zone and create a very active littoral environment. Sediment would be suspended and resettled during each storm event. Maintenance of a dredged offshore channel at its desired depth could become very demanding.

30. Less effort has been made to evaluate the stability of the bayside channel. Based on the results from the tidal current model, the effect of channel improvement could slightly increase tidal current velocity at element 136 (see Figure 6 for element locations) but decrease it at element 118 at the channel route. Even with the change of up to 8 percent, as discussed in paragraph 19, the effect on channel shoaling would not be significant in view of the large net northerly transport water volume. A close examination of Figure 10 will reveal that the northerly current speeds within the bay area are always larger than the southerly current speeds.

Engineering Considerations

31. It is apparent that the maintainability of an offshore channel at its desired depth is a critical engineering concern. Requirement for maintenance dredging could be minimized by increasing the overall stability number Ω/M of Bechevin Inlet. According to Bruun (1978), the natural channel depths, through or over the ebb-tidal delta area, are related to the ratio of Ω/M. For inlets with this ratio less than 60, the offshore stable channel depth could be naturally maintained at 1-3 m. The stable depth will increase to 3 to 6 m when the ratio becomes larger than 100 but less than 150. When the overall stability number is larger than 150, the natural channel depth could be maintained at 6 to 9 m. The overall stability number of Bechevin Bay Inlet may be increased by reducing the M value, the amount of littoral material carried into the inlet. This reduction could be accomplished by the construction of a single shore-connected jetty at the updrift side of the inlet. Figure 13 shows the conceptual layout of the jetty structure. The total length is estimated to be 2.5 miles. This single jetty could reduce the sediment load to the inlet and divert the flood current through the main gorge channel next to Cape Krenitzin. During the ebb tide, this jetty could strengthen the jet action of the ebb current and increase the flush capability of the inlet system.

32. Some of the negative side effects caused by the jetty construction

should also be considered. These include the needs for artificial sand bypassing for the sand trapped at the updrift side of the jetty, possible reduction of tidal prism, accretion at the updrift beach, and erosion at the downdrift beach. Therefore, the final structure layout should be carefully evaluated with model testings.

33. In view of the remoteness of inlet location from the population center(s) of the State of Alaska, both labor and material can become major factors to the project's feasibility. Structural measures (jetty as well as artifical sand bypassing mechanism) for the navigation improvement to Bechevin Inlet may be difficult to justify economically. Furthermore, the lack of site-specific environmental data precludes a reliable mathematical or physical sedimentation modeling effort. Any refinement made to the present analysis probably would not improve the confidence level of the stability assessment. Since the upper end of the overall stability number is slightly above 150, it is possible that the natural forces could maintain the dredged offshore channel at the upper end of the depth range which is 10 to 20 ft without structural measures. The nonstructural plan for the channel improvement is therefore considered feasible but not without a risk of relatively demanding dredging requirement.

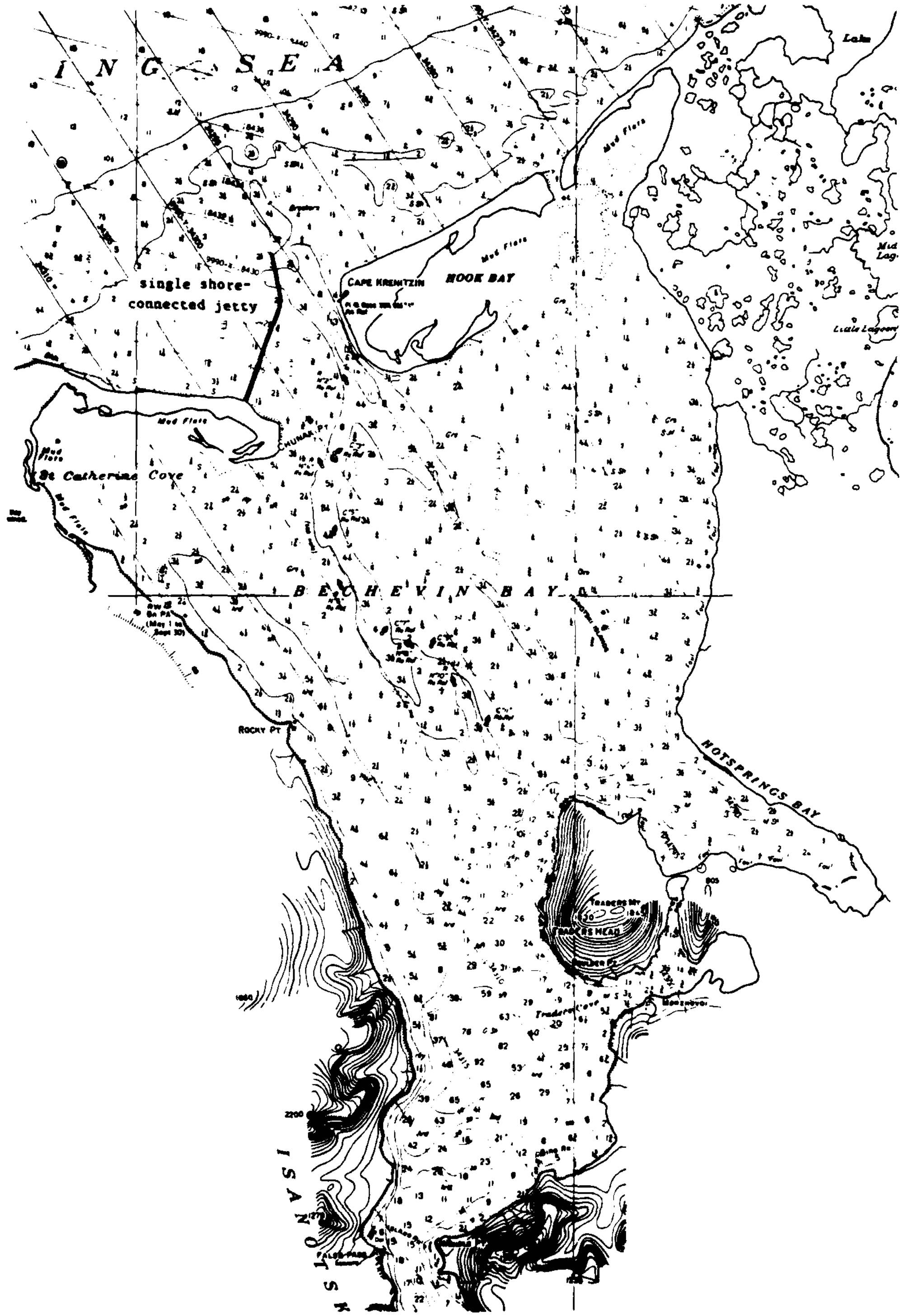


Figure 13. Layout of single shore-connected jetty

PART IV: SUMMARY AND RECOMMENDATIONS

34. The following conclusions and recommendations are derived from the present study:

- a. The littoral environment off Bechevin Inlet is fairly active. Potential gross longshore transport rate is conservatively estimated at 4.9×10^6 m^3/yr, and the net transport rate is 1.05×10^6 m^3/yr with a predominant direction toward the right side of the inlet.
- b. Natural tidal flushing of the Bechevin Inlet system is provided by the strong ebb current and a net flow transport from the Pacific Ocean into the Bering Sea. This net flow transport is estimated to be in the order of 1.3×10^8 m^3/tidal cycle during the spring tides.
- c. The overall stability of Bechevin Inlet was assessed according to Brunn's criteria with a fair stability prediction. Unless the inlet is improved, the relatively large entrance bar over the ebb-tidal delta would be continually in existence. Because of the good flushing ability of the inlet system, a natural channel, 12 ft deep at mllw, can be naturally maintained over the sandbar area.
- d. Improvement on the navigation channel by dredging will slightly increase the tidal prism and the overall stability of the inlet. Shoaling is expected to occur at both the bayside and offshore channels. However, requirement for maintenance dredging will be dictated by the frequency of natural storm events. Significant effort may be needed to maintain the offshore channel at its desired depth.
- e. A single shore-connected jetty structure would improve the overall stability of the inlet and enhance the potential of the offshore channel being maintained at its desired depth. This jetty would be best located at the updrift side of the inlet and extended about 2.5 miles from Chunak Spit into the Bering Sea. An artificial sand bypassing scheme probably would be needed in conjunction with the jetty structure in the overall navigation improvement plan.
- f. The present study is a preliminary assessment. Conclusions and recommendations are derived from the study of existing published data. The overall stability of the inlet should be reassessed when site-specific environmental data become available.

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Table 1

Tide Input for Tidal Current Model

Location	Nodal Number	Surface Superelevation (Referred to the Elevation at False Pass) m	Mean Tidal Level		Phase Lag hr:min		
			Magnitude m	Ratio (Referred to the Height at False Pass)	High Water	Low Water	Average (Referred to the Phase at False Pass)
False Pass	1	0.00	0.73	1.00	-00:47	-01:18	00:00
	2	0.00	0.73	1.00	-00:47	-01:18	00:00
St. Catherine Cove	93	0.15	0.88	1.21	+01:04	+00:49	01:58.8
Bering Sea	120	0.00	1.01	1.39			02:07.8
	121	0.00	0.99	1.36			02:04.2
	131	0.00	1.01	1.39			02:09.8
	132	0.00	0.99	1.36			02:04.2
	133	0.00	0.99	1.36			02:04.2
	134	0.00	1.00	1.37			02:04.8
	135	0.00	1.00	1.37			02:05.4
	136	0.00	1.01	1.38			02:06
	137	0.00	1.01	1.38			02:06.6
	138	0.00	1.01	1.38			02:07.2
	139	0.00	1.01	1.39			02:07.8

Table 2

Maximum Calculated Tidal Current

Time hr	Existing Case Magnitude m/sec	Existing Case Angle deg	25-ft Case Magnitude m/sec	25-ft Case Angle deg	30-ft Case Magnitude m/sec	30-ft Case Angle deg
			At Element 2			
3.5	0.844	94.9	0.848	94.8	0.854	94.7
10.5	0.454	-85.2	0.457	-85.3	0.460	-85.4
16.0	0.622	94.3	0.625	94.2	0.630	94.1
22.0	0.419	-83.4	0.421	-83.5	0.424	-83.6
28.0	0.810	95.0	0.814	94.9	0.820	94.8
35.0	0.442	-84.5	0.443	-84.6	0.446	-84.6
41.0	0.611	94.0	0.615	93.9	0.620	93.8
47.0	0.402	-84.4	0.405	-84.5	0.409	-84.6
			At Element 149			
1.0	0.349	-60.4	0.359	-60.2	0.370	-60.0
6.0	0.868	120.6	0.882	121.2	0.902	121.7
11.0	0.384	-58.5	0.395	-58.0	0.408	-57.6
17.5	0.926	119.8	0.942	120.3	0.964	120.7
24.5	0.595	-60.1	0.611	-59.6	0.630	-59.3
29.5	0.868	120.7	0.882	121.2	0.902	121.7
37.5	0.362	-58.6	0.371	-58.1	0.382	-57.8
42.0	0.854	119.9	0.870	120.5	0.891	120.8
49.0	0.617	-59.8	0.633	-59.4	0.652	-59.1
			At Element 189			
1.5	0.281	-85.1	0.268	-84.6	0.249	-84.0
6.0	0.579	102.6	0.561	101.8	0.532	101.1
11.5	0.232	-75.7	0.226	-76.0	0.217	-76.4
17.5	0.677	101.7	0.655	100.9	0.619	100.2
24.4	0.406	-75.5	0.395	-75.6	0.377	-75.8
30.0	0.579	102.0	0.560	101.2	0.531	100.4
37.5	0.239	-75.4	0.231	-75.9	0.220	-76.3
42.0	0.613	101.9	0.593	101.1	0.561	100.4
49.0	0.412	-77.7	0.402	-77.6	0.384	-77.5

Note: Time is referred to 0000 8 January 1984 and angle to the east direction.

Table 3

Summary of Wave Climates at Bering Sea Offshore of Bechevin Inlet

Significant Wave Height H_o m	Percent of Occurrence, Direction							
	N	NE	E	SE	S	SW	W	NW
0-0.5	1.9	1.7	1.6	1.5	1.3	1.7	1.8	2.1
1-1.5	4.5	4.4	4.4	4.0	3.8	5.8	6.8	6.1
2-2.5	3.0	2.8	2.6	2.7	2.4	3.7	4.5	4.1
3-3.5	1.3	1.2	0.8	1.1	1.1	1.5	1.9	1.8
4-5.5	0.9	0.3	0.4	0.5	0.5	0.8	0.8	0.9
6-7.5	0.1	+*	+	+	--	+	0.3	+
8-9.5	--	--	--	--	--	--	+	--
>10	--	--	--	--	--	--	--	--
Total	11.7	10.4	9.8	9.8	9.1	13.5	16.1	15.0

* Indicates that the wave statistics are less than 0.05 percent but larger than 0.0 percent.

Table 4

Potential Longshore Transport at Coast Off Bechevin Inlet

Wave height m	Q_ℓ, Transport Rate 10 m^3/yr NE	N	NW	W	SW
	Azimuth Angle of Coastline = 52°				
0.25	0.4	1.0	0.1/- 0.4	-0.9	-0.1
1.25	37.1	129.1	18.4/- 67.7	-184.5	-11.1
2.25	102.7	374.1	53.7/-197.8	-530.7	-30.8
3.25	110.4	406.5	57.5/-211.7	-561.8	-31.3
4.75	29.3	726.8	37.6/-138.5	-610.9	-43.1
6.75	--	155.5	-- --	-551.5	--
8.75	--	--	-- --	--	--
Total	279.9	1,793.0	167.3/-616.1	-2,440.3	-116.4

$(Q_\ell)_{southwest} = (279.9 + 1,793.0 + 167.3) \times 10^3 = 2.239 \times 10^6\ m^3/yr$

$(Q_\ell)_{southeast} = (616.1 + 2,440.3 + 116.4) \times 10^3 = 3.172 \times 10^6\ m^3/yr$

$(Q_\ell)_{net} = 0.933 \times 10^6\ m^3/yr$

$(Q_\ell)_{gross} = 5.411 \times 10^6\ m^3/yr$

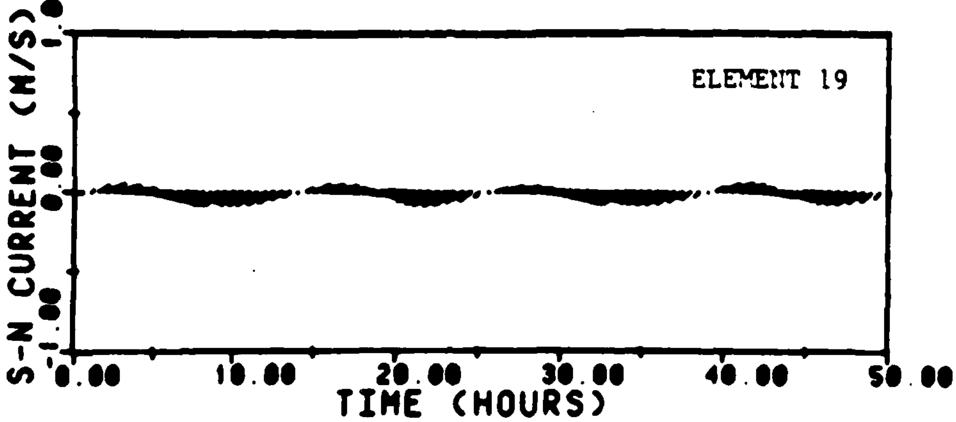
Wave height m	Q_ℓ, Transport Rate 10^3 m^3/yr E	NE	N	NW	W
	Azimuth Angle of Coastline = 90°				
0.25	0.1	0.9	±0.2	-1.1	-0.1
1.25	20.3	127.3	±29.5	-176.5	-31.4
2.25	52.1	352.2	±85.6	-515.7	-90.2
3.25	40.2	378.5	±93.0	-552.0	-95.5
4.75	51.9	203.6	±166.2	-733.1	-103.8
6.75	--	--	±35.6	--	-93.7
8.75	--	--	--	--	--
Total	164.6	1,062.5	±410.1	-1,978.4	-414.7

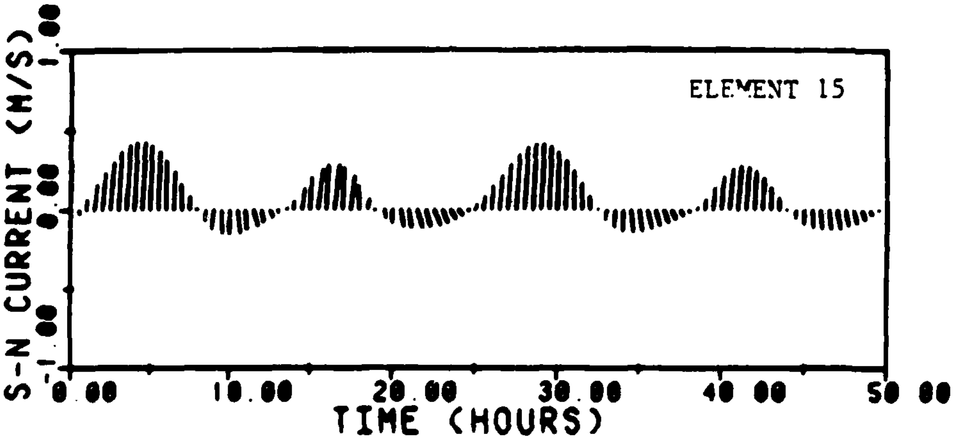
$(Q_\ell)_{west} = (164.6 + 1,062.5 + 410.1) \times 10^3 = 1.637 \times 10^6\ m^3/yr$

$(Q_\ell)_{east} = (410.1 + 1,978.4 + 414.7) \times 10^3 = 2.802 \times 10^6\ m^3/yr$

$(Q_\ell)_{net} = 1.165 \times 10^6\ m^3/yr$

$(Q_\ell)_{gross} = 4.439 \times 10^6\ m^3/yr$


ELEMENT 19
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)


ELEMENT 15
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)

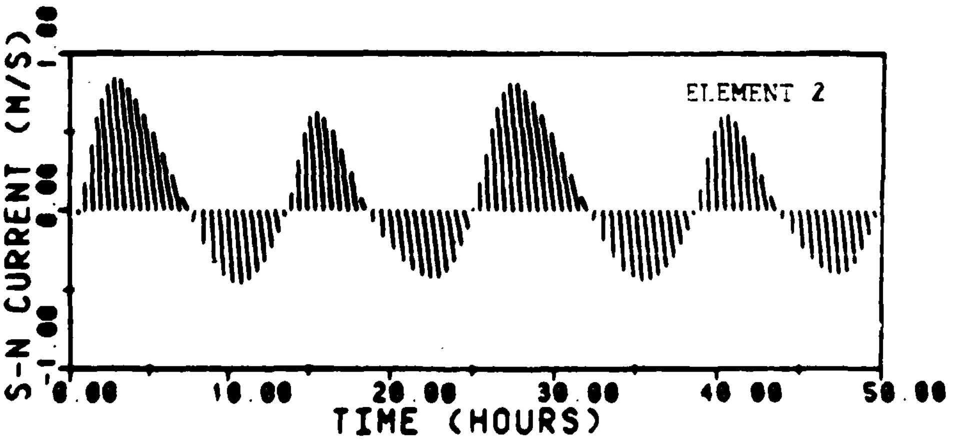

ELEMENT 2
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)

PLATE 1

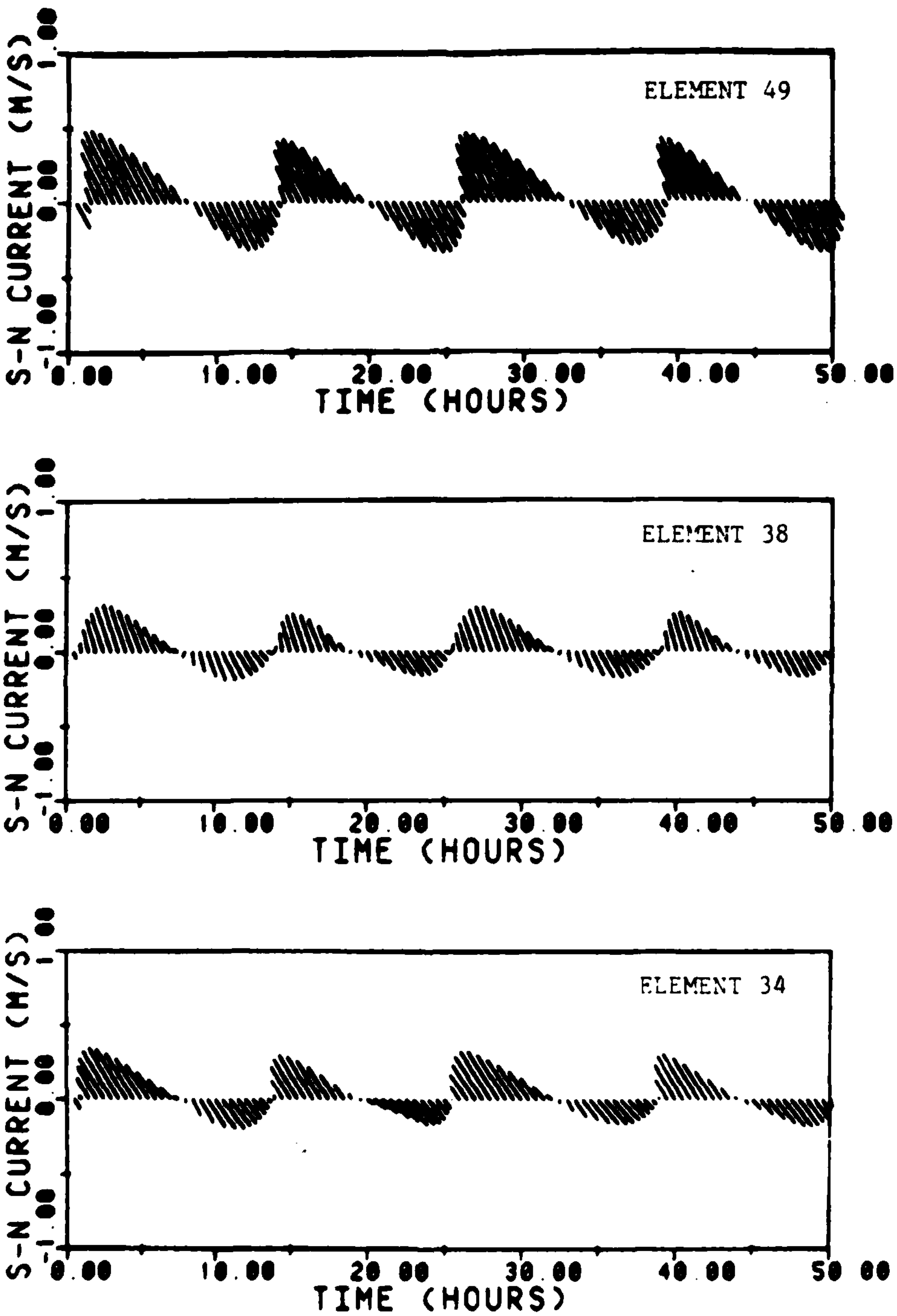

ELEMENT 49
ELEMENT 38
ELEMENT 34
S-N CURRENT (M/S)
1.00
0.00
-1.00
TIME (HOURS)
0.00
10.00
20.00
30.00
40.00
50.00

PLATE 2

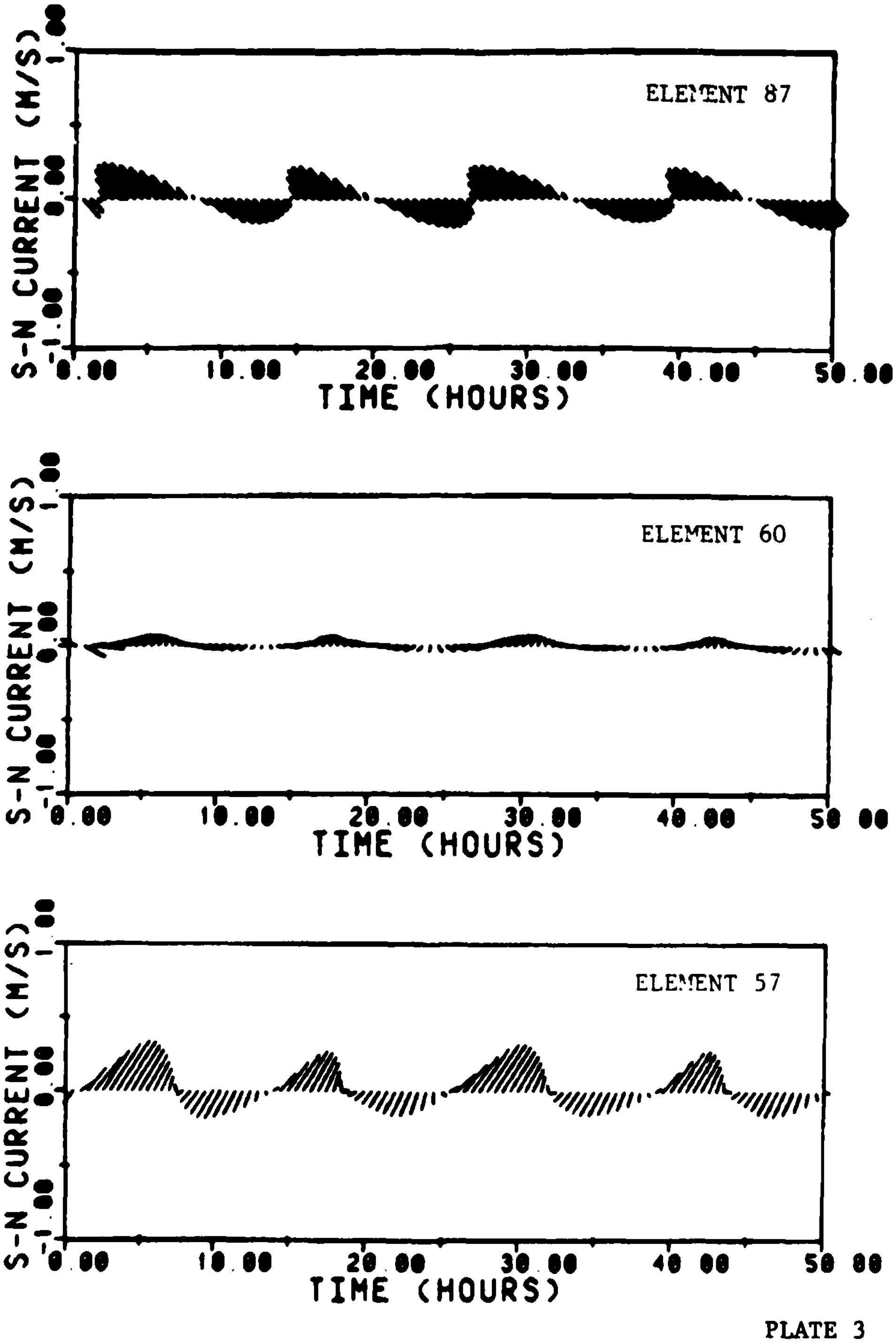

ELEMENT 87
ELEMENT 60
ELEMENT 57
S-N CURRENT (M/S)
TIME (HOURS)
0.00
10.00
20.00
30.00
40.00
50.00
-1.00
0.00
1.00

PLATE 3

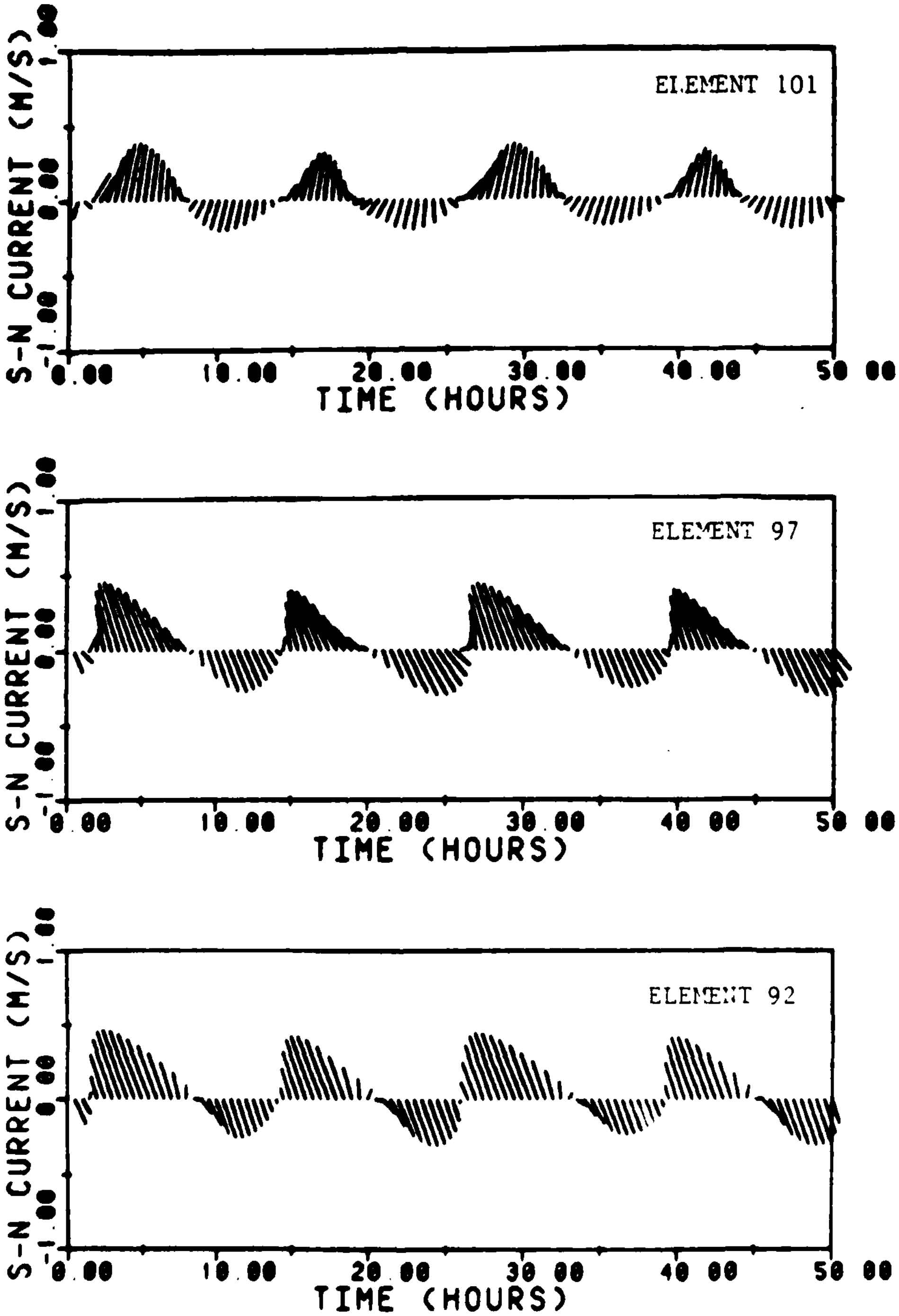
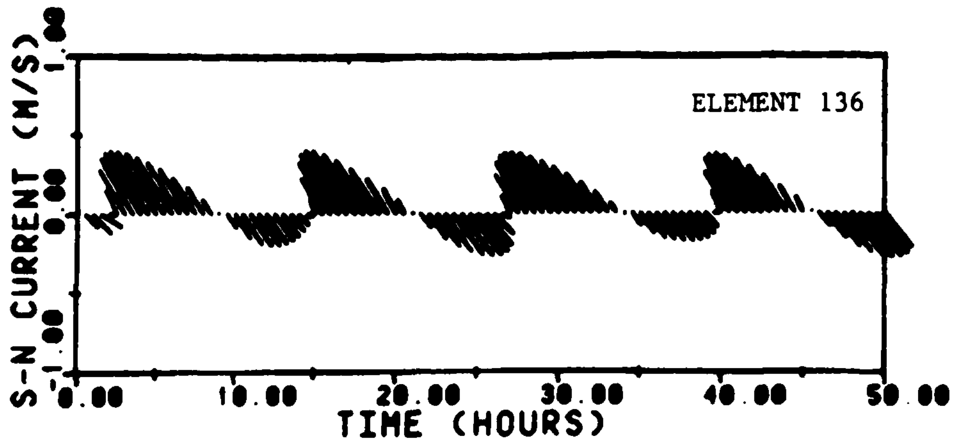
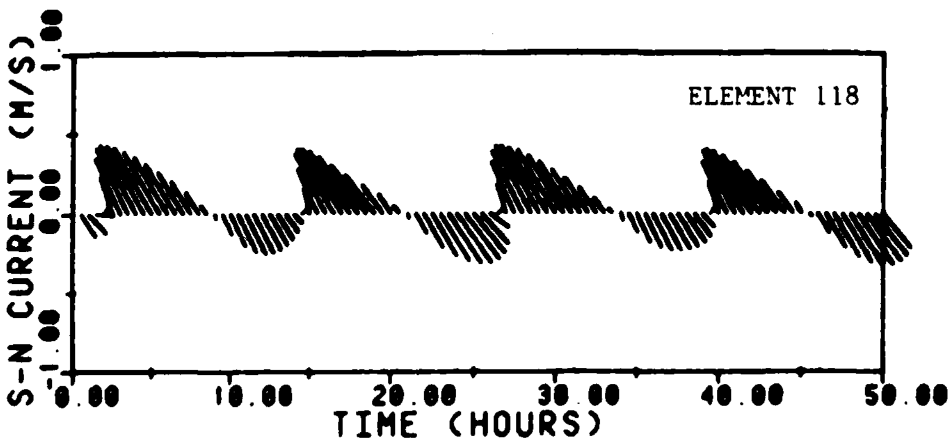

ELEMENT 101
ELEMENT 97
ELEMENT 92
S-N CURRENT (M/S)
TIME (HOURS)
0.00
10.00
20.00
30.00
40.00
50.00
1.00
-1.00

PLATE 4


ELEMENT 136
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)


ELEMENT 118
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)

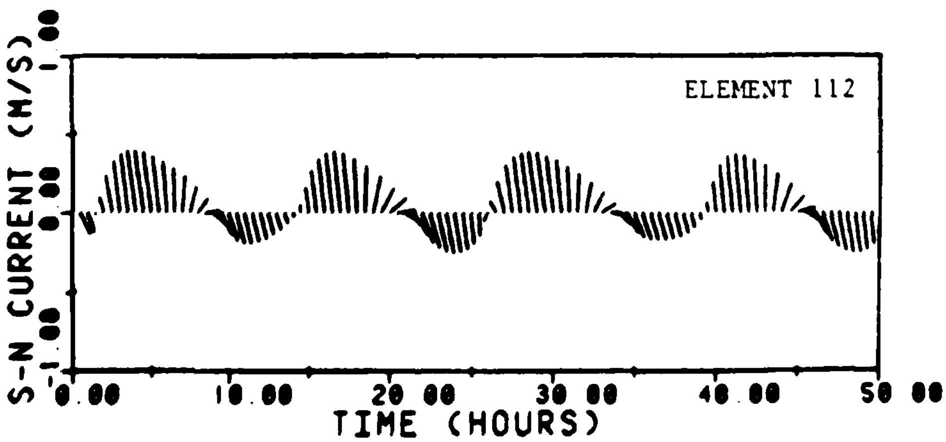

ELEMENT 112
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)

PLATE 5

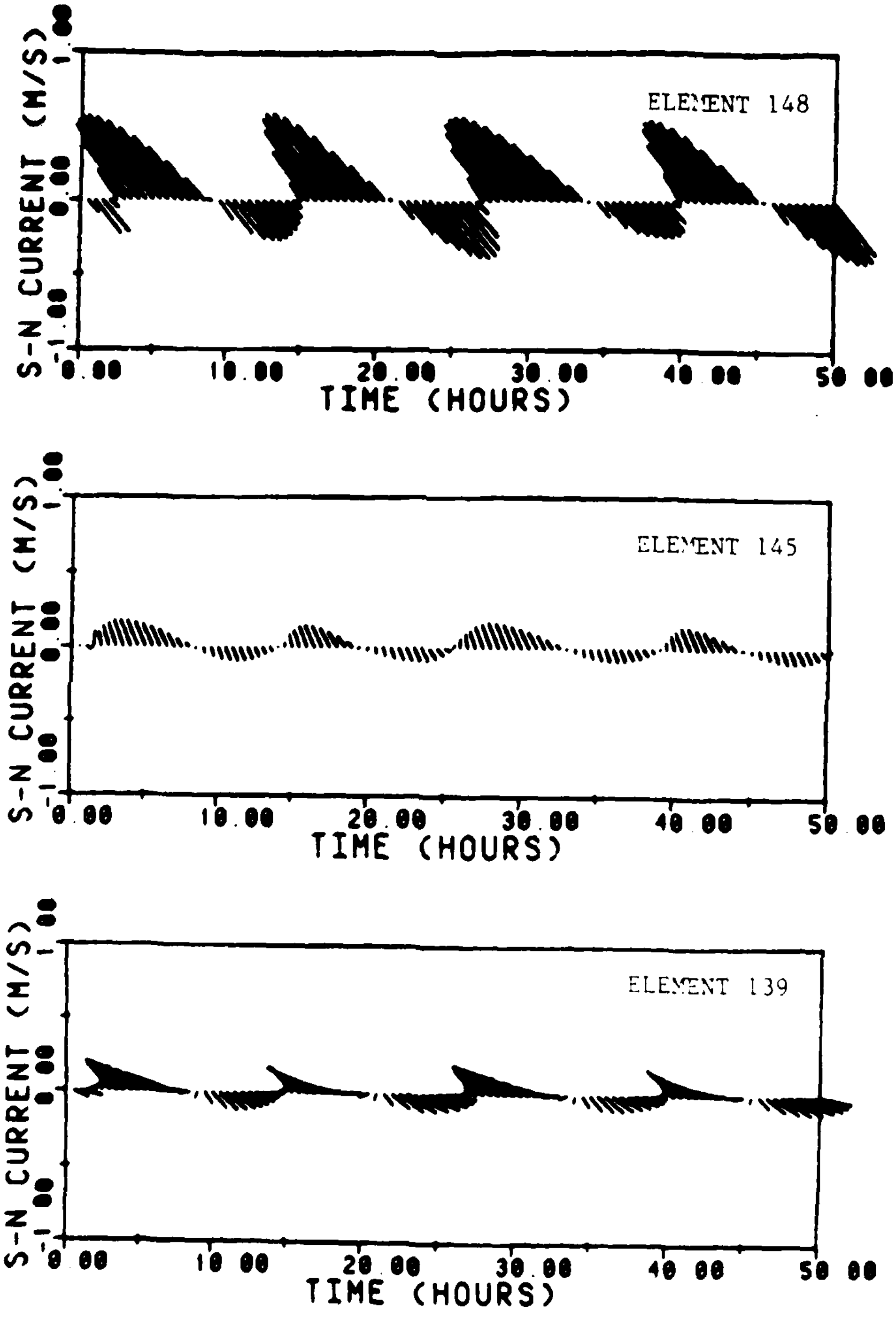

S-N CURRENT (M/S)
ELEMENT 148
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)
S-N CURRENT (M/S)
ELEMENT 145
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)
S-N CURRENT (M/S)
ELEMENT 139
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)

PLATE 6

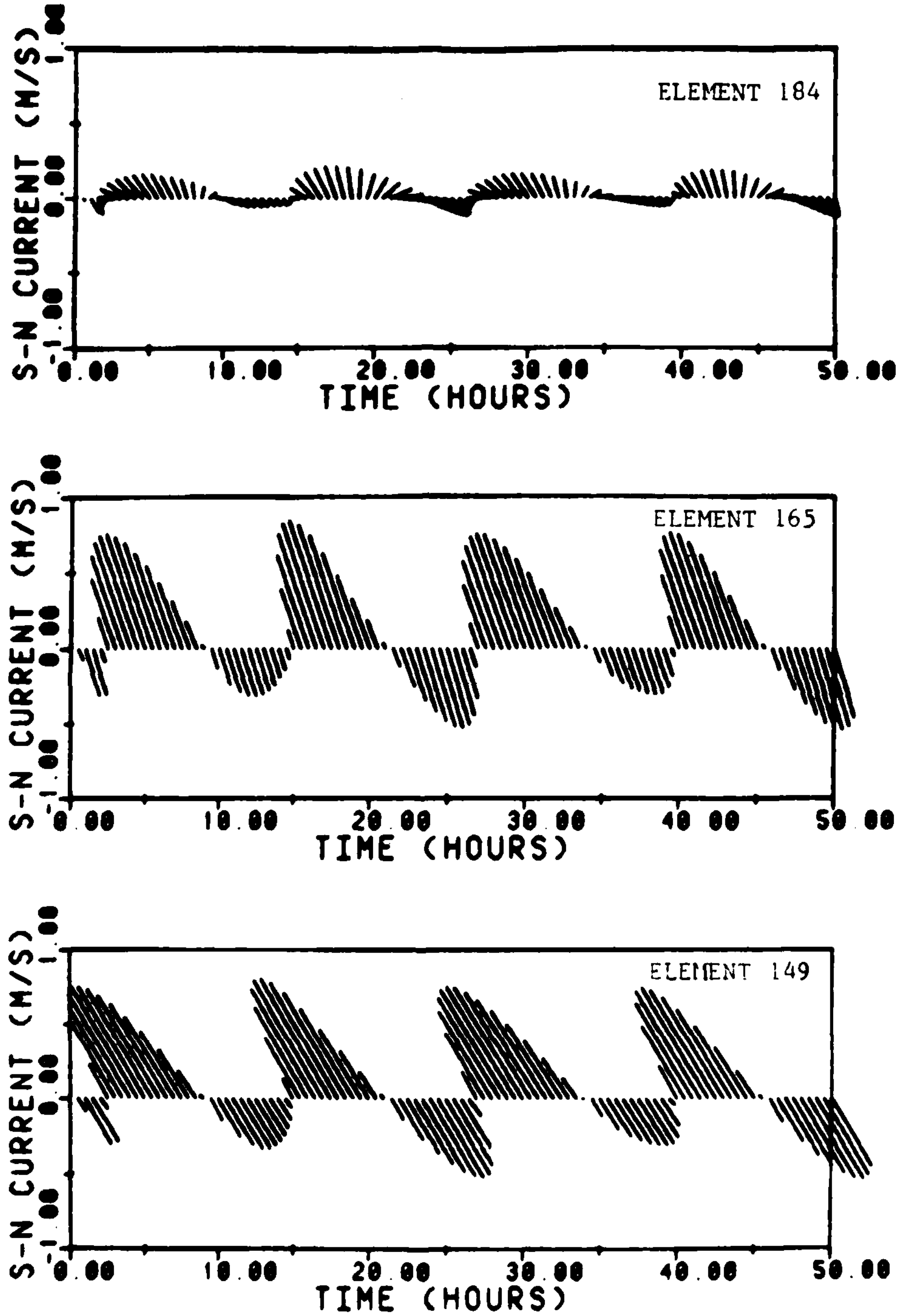
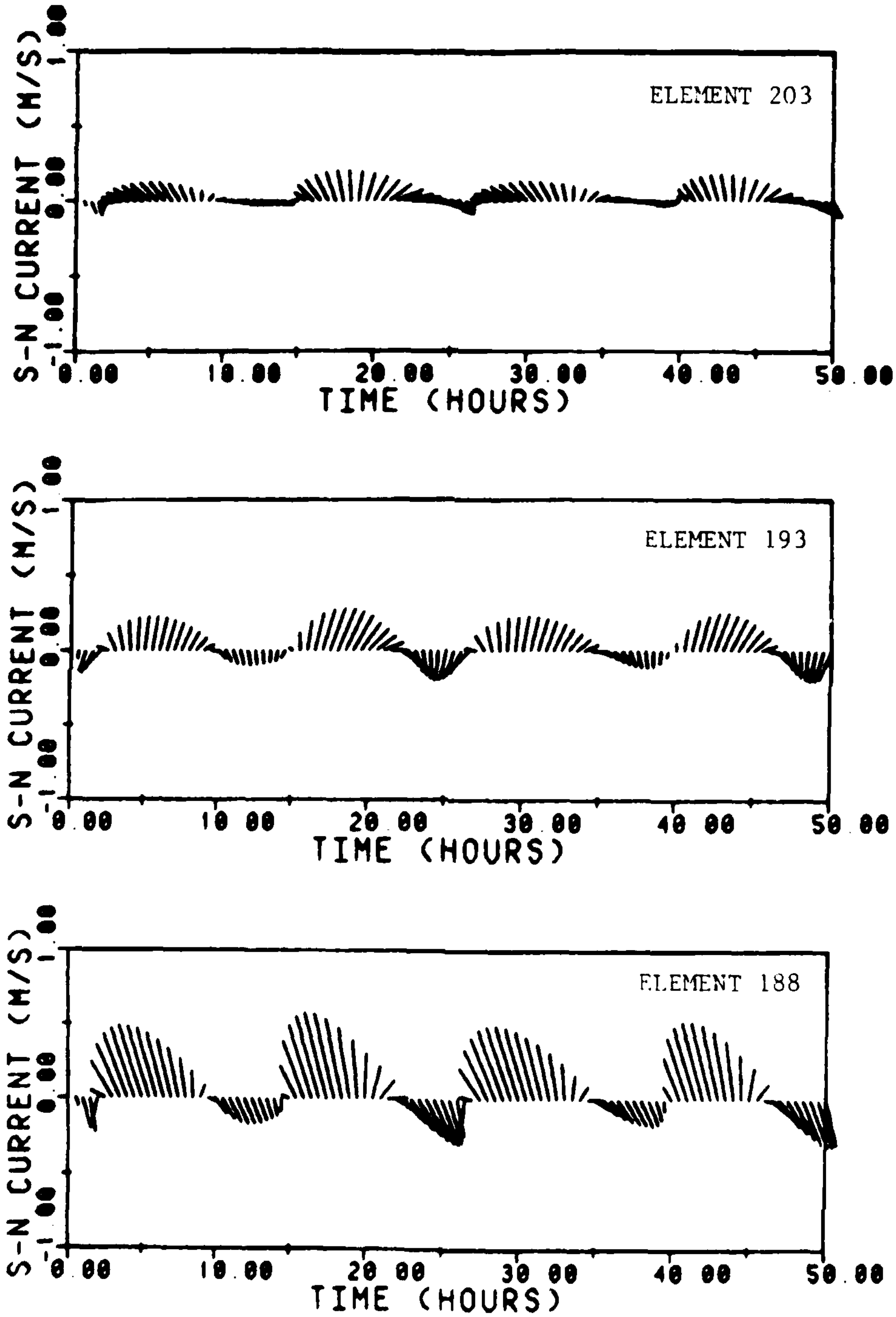

ELEMENT 184
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)
ELEMENT 165
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)
ELEMENT 149
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)

PLATE 7



ELEMENT 203
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)
ELEMENT 193
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)
ELEMENT 188
S-N CURRENT (M/S)
1.00
0.00
-1.00
0.00
10.00
20.00
30.00
40.00
50.00
TIME (HOURS)

PLATE 8

END

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REPRODUCED AT GOVERNMENT EXPENSE